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Environment Consequences of Wood and Other Biomass Sources of Energy

J. F. Coates, Inc.
Washington, DC

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ENVIRONMENTAL CONSEQUENCES OF WOOD AND OTHER BIOMASS SOURCES OF ENERGY

by

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Contract No. 68-02-3642

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Current important research needs whose results will be critical to EPA's mission in the next two to three decades with regard to a major expansion in the use of biomass as an energy source are identified.

Biomass currently contributes about 2.4 quads or 3% to the total national energy consumption of approximately 80 quads. There are no technological limitations of any importance on a 2 to 6 fold expansion of biomass energy to 5-15 quads over the next 20 to 30 years.

The most likely and promising candidate for immediate and longer-range expansion in energy use is wood (5-10 quads) followed by agricultural and food processing wastes and manures in substantially less quantities (0.8-1.2 quads). Exploitation of grasses and crops would comprise the remainder.

The three big risks to the environment and to human health from an expanded use of woody biomass are:

- health risks from residential wood burning;
- toxic air pollution from biomass derived methanol as automobile fuel;
- broad scale disruption of forest ecosystems.

Primary and secondary research and research objectives are defined with regard to these and other risks and opportunities.

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PREFACE

As a key element in anticipating new or newly important environmental problems, the Office of Strategic Assessment and Special Studies of the U.S. Environmental Protection Agency began a mini assessment program. Collectively, the reports under this program are intended to:

- produce a description of alternative future trends and contingencies, and an analysis of their environmental consequences, including effects on public health, the vitality of natural systems, socioeconomic considerations, public welfare and policy implications;
- identify research which should be conducted to support the agency's regulatory mission over the longer term future.

The generic objectives of the mini assessment program, as stated in RFP DV-80-A150, are to assist OSASS by producing a report which will:

- provide a comprehensive, integrated overview of the longer term regional, national, and global environmental outlook;
- expand existing data bases and increase understanding of potentially significant future problems;
- evaluate concepts, models, methods, and environmental controls and policies as they affect the environmental future.

The specific function of each mini assessment will be to explore a potentially significant future environmental problem, and from that exploration:

- summarize the state-of-knowledge concerning the problem;
- define and scope the problem in terms of its public health, public welfare, and environmental policy implications;
- identify major information or knowledge gaps and inadequacies in analytical methods and techniques.

We are pleased to be associated with this intellectually and administratively exciting venture of the EPA. We are doubly pleased to have enjoyed a singularly collegial relationship with our program officers, Dr. Morris Levin and Mr. Charles Oakley, and to have enjoyed refreshing exchanges at the scientific and administrative level with the management and staff of that office.

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Professor Larry Tombaugh of Michigan State University has consulted with us on this project.

Terry Saunders Parsons administered the project and managed the production of this report. She was assisted by Bernice Mann, Margaret McDonald, Rhoda Baum, Kerry Siggard, and Barbara Bullard.

The participants in our workshop and others who helped us with information or in review are acknowledged in Appendix C.

Grant Prillaman was invaluable as a research assistant in the last months of this project.

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Biomass currently contributes about 2.4 quads or 3% to the total national energy consumption of approximately 80 quads. There are no technological limitations of any importance on a 2 to 6 fold expansion of biomass energy to 5-15 quads over the next 20 to 30 years.

The most likely and promising candidate for immediate and longer range expansion in energy use is wood (5-10 quads) followed by agricultural and food processing wastes and manures in substantially less quantities (0.8-1.2 quads). Exploitation of grasses and crops would comprise the remainder.

The three big risks to the environment and to human health from an expanded use of woody biomass are:

- health risks from residential wood burning;
- toxic air pollution from biomass derived methanol as automobile fuel;
- broad-scale disruption of forest ecosystems.

Primary and secondary research and research objectives are defined with regard to these and other risks and opportunities.

This report was submitted in fulfillment of Contract No. 68-02-3642 by J. F. COATES, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 29, 1980, to July 15, 1981, and work was completed as of April 22, 1982.

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SECTION 1

FINDINGS AND RECOMMENDATIONS

As a key element in anticipating new or newly important environmental problems, the Office of Strategic Assessment and Special Studies of the U.S. Environmental Protection Agency began a mini assessment program designed to provide a comprehensive, integrated overview of the longer term regional, national, and global environmental outlook with respect to certain potential problems. The mini assessments are to summarize the state of knowledge concerning the problem, scope the problem in terms of its implications for public health and welfare and environmental policy, and identify major information gaps and inadequacies in analytical methods and techniques. This mini assessment is concerned with the increased use of wood and other biomass sources of energy.

INTRODUCTION

The mini assessment is based on review of over a thousand documents selected from the vast literature on biomass. The study strategy was to attempt to throw biomass into these perspectives: Sec. 2*

- what is practical now and over the next generation -- the next twenty-five to thirty years;
- what are likely to be the main kinds of environmental consequences -- good, bad and uncertain -- of a substantial move to biomass for energy.

No attempt was made to trade off economic, environmental, or other objectives with other energy sources (e.g., biomass vs. geothermal energy) but only to suggest the relative importance of objectives and consequences within the framework of biomass. The mini assessment takes into account the implications for other agencies and levels of federal, state and local government.

The project did not undertake original field or laboratory research. It relied upon examination, collation, and analysis of the published research findings of others. A synthetic and critical examination of those reports is our contribution to the policy and

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*See Section 2 for details.

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research planning discussion. The team used broad review by experts and potentially affected parties in a broad outreach to collect, correct, and organize materials and critique findings and recommendations.

The most likely and promising candidate for immediate and longer range expansion in energy use is wood, followed by agricultural and food processing wastes and manures. The purpose of this study is to provide guidance to EPA on practical research issues. We judge on the available evidence that liquid fuels directly yielded by marine, and aquatic plant sources, and biophotolysis (the direct production of hydrogen) are not practical contenders for extensive development in the next decade or so. Furthermore, should developments make these alternatives sharply attractive or suddenly modify their technical-economic feasibility there should be ample time to study and evaluate their environmental effects. They are not covered in this report. Urban refuse is concern of solid waste programs and is also excluded from this report. Sec. 2 p.17-20

Sec. 4 p.48-52 Since OSASS/EPA has a separate study underway on alcohol fuels from biomass, they are excluded from this report. Specifically excluded is discussion of ethyl alcohol, i.e., alcohol from crops and grain, or other fermentation processes leading to gasohol. We avoid the economics of inter-fuel competition of biomass, which are uncertain and in rapid flux. Furthermore, government policy -- as it always has with energy and other resources -- has a strong influence in creating incentives and disincentives to use biomass. It is our belief that should biomass in the long term become a factor of major importance to our net energy consumption the macro-economics of its use will have little influence on environmental effects. Ignoring economics is also appropriate, since the transition problems in the growing use of biomass are outside the scope of this study. This report deals with the long-term environmental effects of a massive increase in the use of biomass by the year 2000.

To forecast a reasonable and useful range of use of biomass as an energy source over the next several decades, one would normally expect to rely upon solid background forecasts of overall energy demand and supply. Against that background one would begin to forecast the alternative market penetration futures for biomass energy. The latter forecasts would be based upon technical and economic considerations and assumptions about stable public policies. Unfortunately, none of these conditions exist to permit reliable forecast of aggregate biomass demand.

We come to what we take to be a commonsense conclusion with strong consensus from a large number of analyses that the most significant biomass energy source for the next decade is wood, with crop waste as the supporting source. Sec. 4 p.40

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Future Use

Biomass currently contributes about 2.4 quads or 3% to the total national energy consumption of approximately 80 quads. There are no technological limitations of any importance on a 2- to 6-fold expansion of biomass energy to 5-15 quads over the next 20 to 30 years. Sec. 4 p.52-59

The most likely and promising candidate for immediate and longer range expansion in energy use is wood (5-10 quads) followed by agricultural and food processing wastes and manures in substantially less quantities (0.8-1.2 quads). Exploitation of grasses and crops would comprise the remainder.

The expanded use of wood for energy will occur in five areas:

- meeting the energy needs internal to the forest products industry, which already meets 55% of its energy requirements from wood;
- in central power stations outside the forest products industry;
- direct combustion in fireplaces, stoves, and furnaces for space heating or hot water in homes and small commercial establishments;
- gasification in small facilities for immediate or highly localized use;
- gasification in large facilities to provide a substitute for natural gas in pipelines;
- pyrolysis, a much lower likelihood use.

The most significant conversion technologies reflecting those uses are:

- direct combustion in homes and small commerical establishments;
- direct combustion in boilers;
- airblown gasification.

Methanol can be produced from wood by several routes and is being touted as a substitute for gasoline. As discussed below, the potential environmental health and safety risks associated with that fuel use are so critically important that their resolution should take precedence over all other problems connected with methanol production for automotive fuel. Until these risks are addressed, methanol for fuel is neither likely nor promising. Sec. 5 p.60 Sec. 7 p.94-96 124-25

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FINDINGS AND RECOMMENDATIONS

The principal findings of this study lead to recommendations for EPA alone, or in cooperation with other federal agencies, state and local governments, or with the private sector.

The recommendations, by the nature of the study, are directed at potential issues likely to become important in the next two to three decades with regard to the environment, human health and safety, or the technoeconomy. The recommendations share four characteristics:

- o they relate to major issues and impacts of biomass;
- o early action is needed to better understand the situations;
- o knowledge from research and development would provide useful and timely information with regard to policy, implementation, the selection among technological alternatives, and regulations or its alternatives;
- o the recommendations deal with those matters which, if government fails to act, would lead either to a serious problem in American society, or deprive society of a substantial benefit.

The recommendations are of two general sorts: the first are unequivocally within the province of the Environmental Protection Agency and its presently constituted legal authority and customary research interests. The second, by virtue of dealing with futures issues, impinge on responsibilities which are often uncertain, cross jurisdictional or agency lines, and suggest in many cases that innovative approaches are required to cope with the future impacts. With regard to the second category, only the sketchiest attempt is made to determine who should act, when, and in what capacity. We believe that it is sufficient to highlight critical problems and the actions necessary to deal with them. Whether EPA or other agencies choose to act on this information is, of course, their decision.

There will be no significant nationwide direct environmental effects of an extensive use of biomass, based on either wood or agricultural products. There are, however, potentially significant local and regional, direct and derivative effects, particularly from the extensive use of wood biomass at the production and consumption ends of the wood energy cycle.

The principal environmental effects in all these regards will be localized or in relatively small regions. (Note: the term "region" is not used here in the sense of federal regions but in the sense of a locale larger than a city or county and running up to a state or a multi-state area.)

Concerning the regional use of woody biomass, the most attrac-

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tive areas from a biological point of view -- that is, the rates of production of wood -- are in the Northwest (Washington and Oregon) and the Southeast. However, from the point of view of land values in competing uses, these are also the highest land value areas. The balance point for optimal development of biomass may be in the North Central area and New England.

Sec. 6
p.75-77

Three Big Risks

Sec. 8
p.100-
163

Of the hundreds of effects consequent upon the development of a new energy facility, the overwhelming number of them will be readily handled in the framework of the present planning processes such as Environmental Impact Statements and the various local county and state and federal specific planning requirements. There are well established mechanisms for probing, exploring, and evaluating effects associated with the planning, design, construction, operation and disposal of energy facilities.

The three big potential new risks to the environment and human health from an expanded use of woody biomass are:

- o health risks from residential wood burning;
- o toxic air pollution from biomass derived methanol as automobile fuel;
- o broad-scale disruption of forest ecosystems.

Wood Combustion and POMs (polycyclic organic matter)

Sec. 8
p.137-
156

The greatest potential human health risk from the combustion of wood is from POM produced in residential home combustion. The POM is known to be present in substantial quantities in smoke and particulates from wood burning. They are known to bear carcinogens and carcinogenic-like materials. The evidence is unclear as to what the risks are indoors or outdoors to citizens regularly exposed to wood smoke. This seems to be the central health problem which must be resolved before any control strategies can be considered or before any other risks, such as smoke and haze, can be thrown into policy perspective.

> We recommend that the EPA undertake a two-fold program: one, an intense program to define the cancer or other serious long-term risks of POM.
>
> We recommend as the second arm of the proposed strategy to prepare for varying degrees of bad news coming from the first project, an accelerated effort should be made cooperatively with industry to define the alternative means by which technology may be brought to bear to reduce the risks of or to control and mitigate the exhaust from fireplaces, stoves and furnaces.

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There are other potential significant environmental and health problems associated with use of residential wood for heating. In particular, we see that many citizens, particularly those at the lower end of the socio-economic scale, with the fewest resources and likely to be least readily affected by the availability of information, are likely to be tempted to use materials other than clean wood, such as treated wood, scrap wood, wood containing paint or pentachlorophenol, newspapers, plastic, crank-case drippings, or other material as fuel.

> _We recommend_ that EPA through a collaboration with the Center for Disease Control, using public surveys, attempt to assess the extent to which damaging materials are burned. Related but perhaps not as pregnant with acute implications is the use of coal in stoves not designed for coal combustion. Attempts should be made to assess the scope of that application.

> _We recommend_ together or independent of the above, an examination, perhaps again through the auspices of the Center for Disease Control, of epidemiological data from other advanced nations where wood burning has been widely used to determine what if anything is known about the consequences.

The Wood Combustion Working Group at The Research Triangle Park

The wood combustion working group at Research Triangle Park, EPA, is highly and widely regarded as an extremely useful information center for industry, government, and all others connected with the small-scale wood combustion problem.

> _We recommend_ that work with this group be expanded, that it be made a national center for understanding the technology of small-scale wood combustion. While we are not now in a position to suggest the scope and scale of the new work, it is recommended that EPA begin immediately to define and to expand that program in innovative ways to support and interact with the private sector.

Methanol - An End Use Health Hazard

There is no question that methanol can be produced from biomass by several routes, in particular from wood by gasification. p.124-5
p. 95-6
There may be significant environmental problems associated with the production and conversion to methanol, in view of the scale of production which would be necessary to have significant consequences on gasoline consumption, but those problems can be deferred until a crucial end use question is answered. Methanol is highly toxic. It oxidizes in the body to formaldehyde which is selectively toxic to nerves. It is widely known that selective toxicity by methanol can lead to blindness and irreversible

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neurological damage. The current standards for the evaluation of automobile emissions have been premised on gasoline and diesel fuels each of which when emitted in uncombusted form creates relatively low toxicity problems, although they lead to subsequent environmental pollution by oxidation. A substantial percentage of vehicles are out of tune, and the regulation of such vehicles is extremely difficult, if not totally impractical. We believe that the toxicity problems in end use methanol must be accurately and fully defined before any substantial national commitment is made to methanol from any route. Once large investments are in place it is unlikely that a straightforward evaluation of potential risk can be made and acted upon.

> We recommend that EPA begin a systematic structured program to define the human health risks of methanol when used in vehicles, paying particularly close attention to the highly practical factors of out of tune, defective vehicles, and concentration in special environments, parking lots, gas stations on hot summer days, etc.

The Broadscale Disruption of Forest Ecosystems

On the production side, to meet a two- to five-fold increase in wood for energy consumption implies increasing harvesting of forest residues, unmerchantable wood, and other materials now wasted, more intensive management of forests, the introduction of new varieties and species, the introduction of short rotation and intensive cultivation of crops, and ultimately a movement from multi-purpose forests to energy farms. Insofar as forest management is an example of applied forest ecology, the knowledge base, the skill, the experience now at hand, is inadequate to justify confidence that we can move in these desirable directions safely and with dispatch. The widely recognized risks to the forests are associated with silviculture and harvesting, and include soil depletion, excessive run-off, removal of nutrients, irreversible changes in the characteristics of the forest terrain, the pollution of rivers, siltation, effects on aquatic life, and aesthetic changes in the forest. p.104-122 p.162

> We recommend that the EPA, jointly with the Forest Service and Forest Products Industry, sponsor a major three-month summer study to define the status and the steps needed to make forest management an effective branch of applied ecology. Perhaps more valuable and on a larger scale would be a six to nine months commission involving both public and private members to accomplish the same objective. When one realizes that we are seriously considering as much as one-fifth of the nation's total energy supply, twenty years from now, these kinds of stock taking and planning investments are trivial in terms of potential payoff.

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We recommend that EPA sponsor or co-sponsor with the DOE and the USDA an invitational research seminar drawing together interested stakeholders, including paper and pulp companies, state forest officials, and others, to authoritatively define the areas of uncertainty in need of research, in need of management innovation, and in need of other kinds of policy actions with regard to the management of forests for a larger scale production of energy.

The Need for Experimental Managed Forests

Sec. 8 p.100-118

The principles of ecology tell us that the whole is more than the sum of the parts, that characteristics emerge out of complexity that are not apparent or even discernable merely by understanding the individual elements. The principles of ecology also tell us that the individual elements and their significance can only be understood in the context of the whole. If industry moves to larger scale harvesting and on to managed forests for single purposes, the greater intensivity of intrusion on the forest will demand a broader, more integrated base to put that management on a sound footing. It is essential to long-range management that we have test beds for discovery and experimentation which match the scale and complexity of the natural and managed forests. There is no way to build the necessary knowledge except through comprehensive long-term systematic observation and intervention.

We recommend, therefore, that EPA jointly with the USDA Forest Service and the Department of Energy work collaboratively with one or more private sector companies to set up several experimental forests representing varying degrees of intensivity and intrusiveness of management.

We recommend, in view of the fact that industry's silviculture practices are not well and clearly understood, a joint public/private venture to explore those practices.

An Experimental Energy Plantation

Sec. 8, and p.84

In making the jump from a two-fold to a five-fold increase in biomass, almost certainly some forest will have to be put on short rotation and dedicated almost totally to production of biomass for energy. In the short term, the bulk of biomass for combustion will come from waste scrap and residuals. The research to date makes it rather clear that effective energy plantations or energy farms would have to be big. Again, following the principles of ecology we see no hope of understanding what is implied by such large-scale activity unless the activity is undertaken on a large scale. This well recognized chicken and egg dilemma we believe can be satisfactorily resolved in the public interest through a joint public/private sector venture to set up one or more energy forests, either

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complete in themselves or as adjuncts to more conventionally managed forests.

> We recommend that the EPA, USDA, DOE, and private sector make a long-term commitment of public land to such purpose in order to economically justify the construction and operation of a wood burning central power station. It is well known that in the utilities industry, guarantee of supply is essential to any long-term venture. Consequently, the public involvement could provide the key ingredient, guarantee supply, and plan the observations and experimental elements necessary to establish an information base to determine future public policy toward energy farms.

Forest and Environmental Data Bases

It is not clear the extent to which the environmental data bases with regard to silviculture are inadequate and the extent to which they are just inadequately organized, collated, and presented to public and commercial foresters, to environmentally concerned organizations, to state and local public bodies and others concerned with applied forest ecology silviculture and harvesting. Sec. 8

> We recommend that EPA jointly with the U.S. Forest Service and collaboratively with the private sector define present and desirable data bases and lay out a systematic program to collect and organize them. The program should be framed around present and future user needs. Therefore, this planning should be participatory. The data should be reduced to a form which will be useful, not necessarily encyclopedic.

Risks from Land Owners and Small Forest Lots

Fifty-eight percent of the commercial forests of the United States is in the hands of non-industrial private land owners. In Tennessee, for example, 87% of the privately owned forest lands are lots under 50 acres. Private owners generally do not have the overriding long-term incentives for effective management that forest industries do. Even if they have the knowledge and ability, as few of them do, to manage lots productively, many may be tempted to permit destructive harvesting as the price of wood goes up in order to reap short-term benefits.

> We recommend that EPA, in conjunction with the Forest Service and appropriate regional agencies such as TVA, accelerate its monitoring of the role of the small private woodlot in forest energy, build a data base on actual rates and modes of harvesting, and begin to explore innovative ways of gathering information and institutionalizing the effective management of these

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small lots. For example, harvesting co-ops may be a means of providing short and long-term benefits to small land holders. The current work of the TVA under the joint sponsorship with the EPA is developing some effective models for information transfer to small lot owners.

Genetics

The pace of interest in improved plant breeding is picking up in the forest products industry. There is interest in improved varieties, new species, improved pest and disease resistance, plants with shorter growth cycles, and many other improvements. Emphasis is on traditional plant breeding, although there has been substantial success in the application of tissue culture techniques to Douglas fir, redwood, pines, and others. The application of more advanced genetics engineering techniques, such as protoplast fusion, transferred DNA clones and foreign vectors, and the culturing of plant cells and embryos, has not been as conspicuously and widely applied in tree genetics as it has in other plants and microorganisms. Both the size of the benefits and the risks implicit in genetic modification of forest gene pools suggest that more systematic and structure address should be given to these questions. p.33-34

> We recommend that EPA in joint sponsorship with the Department of Agriculture/U.S. Forest Service, the Department of Energy, major forest related professional associations, the forest products industries, state officials, international related bodies of the U.S. government, and a major plant and genetic research institute meet in extended conference to define and recommend a national plan on forest genetics. Such a conference would suggest a useful division of labor, give a long-term focus to these opportunities, and help in the most effective allocation of public and private responsibilities in this area.

Pelletization

Technologies for densification and pelletization may increase the effective range over which wood can be used both on an industrial and a residential basis -- in the latter case, for use in stoves and furnaces. A uniform size product will lend itself to more regular use in furnaces and the use of automatic stokers. It may also lend itself to more ready use in residential fireplaces and freestanding stoves by being more convenient to package, deliver, store, and handle. Pelletization and densification may expand the geographic market for woodburning, thereby expanding any associated environmental and health risks.

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> We recommend that EPA jointly with the industry and Forest Service monitor this market.

Technology and Environmental Risks Management and Control

The technologies of silviculture and harvesting are dominant factors in the extent to which the forest is maintained or degraded. Sec. 8
Many people in the forest products industry feel very confident that the industry can handle intensive forest management quite comfortably. On the other hand, there is a wide consensus that the present problems of understanding forest management are in a state of disarray because of inadequate data on effects, inadequate measurements, inadequate monitoring technology, inadequate systems for data collection and data reduction, and poor models. A two- to five-fold increase in forest energy harvesting would have substantial effects on the technology and would stimulate substantial innovation in new equipment and uses.

> We recommend that EPA jointly with the Forest Service and collaboratively with industry hold a conference on forest technologies for management, monitoring, and control. Among the topics which might be discussed by such a conference might be:
>
> - the role and need of new size and kinds of harvesting and manipulative equipment;
> - uses of advanced technology, e.g., encapsulation, to the application of nutrients to the forest;
> - the role of telecommunications and computer technologies, particularly microprocessing in field monitoring, data handling, modeling, and information access;
> - the application of microprocessors to small and medium sized gasifiers;
> - assessment of forest residues;
> - technology applied to aesthetics and visual implications of alternative forms of forest management.

Gasifiers and Central Station Combustion Technology

Without question, there will be environmental problems associated with the expanded use of wood in central stations generating electricity or steam. p.86, p.92
Similarly, there would be environmental problems associated with the widespread use of large, medium, and small-scale gasifiers. We, however, see no problem associated with that technology which is new or unfamiliar, or any unprecedented or

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unexpected difficulties. The state of technological development, present environmental constraints, and economic factors are likely to take care of major user problems.

> We recommend, therefore, that EPA in conjunction with USDA and DOE keep abreast of the technology and its use but take no other action now.

Manures and Agricultural Processing Wastes

The use of manure and agricultural and processing wastes as energy feedstock is not likely, at any scale, to make any significant contributions to the net energy balance of the nation. Their use as biomass energy can become, however, one of a number of choices significant to the individual farmer and to operators of large-scale animal feeding facilities or food and fibre processors. p.177-81

There is no evidence for serious environmental problems originating from the use of crop residues for energy generation. The nation is not likely to be swept by biogas or biomass technology at such a rate that any now obscure effects of that technology could overtake us.

> We recommend that EPA, in conjunction with the USDA, monitor the development of the conversion technology of gasification anaerobic digestion, and anticipate beginning low level observation on environmental consequences when that technology comes into use.

Labor Force Projections

There seem to be no major satisfactory trend projections in regard to labor force requirements in the forest products industry. There are now approximately 100,000 foresters. Should an expansion by two- to five-fold for energy occur, there will be great demand for information and guidance throughout the silviculture cycle. It is widely recognized that the amateur hands often are the heaviest hands in the management of environmentally sensitive matters. Consequently, effective environmental management will require a trained and fully informed workforce.

> We recommend that a labor force demand study be undertaken jointly with USDA and DOL with particular attention to alternative ways in which foresters might serve their client community through extension programs, short courses, advisory mechanisms, and the formation of new kinds of institutional units for forest management.

Market Distortion

There is the significant possibility of major indirect environ- p.168-74

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mental effects which may result from distortions of the market by federal policy interventions, and the consequent substitution of effects which may result. In-depth policies which promote high turnover of wood may affect international export markets for high quality hardwoods, notably walnut and white oak. Also, we may find ourselves in the ironic position of promoting the use of wood to produce energy, which in turn will lead to the substitution for wood by aluminum or plastics which may carry a higher net energy content. The substitutes may be more environmentally intractable as solid waste disposal. It is important not to create conditions through government intervention that create false economics for energy biomass. For example, we must be careful not to create circumstances in which it will be more profitable to use veneer logs for energy than for veneer. There must be a concerted effort to understand the effects of proposed policy or regulatory programs so as not to adversely disrupt existing market forces which are already well understood by established biomass related industries.

We recommend that EPA monitor any proposed legislation related to biomass energy and be prepared to do economic analyses of effects on price structure in the forest products industry and of resulting substitutions.

Chemicals from Biomass

Through well established and new conversion routes, biomass can be converted to chemicals of large-scale industrial importance. p.160 Insofar as these conversions to chemicals merely produce chemicals now in commerce on a large scale, their use presents no new problems or opportunities. On the other hand, should new chemical industries develop based upon cellulose lignin, terpenes, or other plant materials, they may present substantial and marked environmental advantages or hazards. Being natural products, one would expect that natural processes would be able to biodegrade them. On the other hand, to make reasonably durable final products for many purposes, they would be processed into chlorinated or other derivatives. Those derivatives, by virtue of being naturally derived, may be anti-metabolites, that is, blocking agents for fundamental processes in living organisms. There simply is not enough knowledge available now to determine which of these outcomes is of any significance.

We recommend that EPA convene a small premier working group of plant chemists, biochemists, and environmental scientists to consider the merits of this argument and to define any particular experiments necessary to determine whether public policy action should be taken to encourage or discourage biologically based new chemicals.

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The Benefits of Biomass

The benefits of biomass as an energy source are almost entirely contingent upon two factors. First is the ability to establish biomass resource management procedures which assure the renewable characteristics of the resource. As already stated, this implies the development of a better knowledge base in applied ecology and a reduction of that knowledge to effective practice. Second is an active policy to establish and implement objectives promoting wood use, putting it into fair competition with other fuels without destroying the economics of the forest products industry. The expanded use of biomass to any degree commensurate with its practical availability could significantly relieve our foreign oil import requirements.

There will be some small but locally significant environmental benefits from an expanded use of biomass. Among these are:

- better forest management in many areas through the removal of residues and debris;
- more satisfactory disposal of wastes such as manure and food processing wastes;
- the cleanup of parks and forests through more systematic harvesting of small local quantities of wood for residential combustion.

The benefits of biomass development on rural America, however, are almost totally contingent upon the establishment of continuing successful forest resource management procedures. In the absence of effective management, the rural situation will only worsen.

Global and International Aspects of Biomass Energy

Sec. 11 p.184-192

Whereas biomass is an opportunity for the United States, in the Third and Fourth Worlds it is an increasingly critical problem. Firewood has been referred to as the poor man's energy crisis. Other problems of unprecedented scope lie before us:

- carbon dioxide pollution of the global atmosphere;
- world-wide deforestation;
- conflicts between land for food and for fuel;
- unwise introduction of plant species into various regions of the world.

On the other hand, there are potential benefits to the United States in closer attention to global and environmental biomass issues.

- o transferable lessons to the United States from other advanced industrial nations and possibly from the Third World;
- o more effective use of U.S. resources in foreign assistance;
- o new opportunities for foreign trade hinging on products, technologies, and information.

> We recommend that EPA request that OMB reassess its international and environmental responsibilities in biomass energy. The present assignments of responsibilities among agencies does not inspire confidence that a sound knowledge base is being developed in our long-term national interest.

Administrative Orientation

Sec. 2
p.16-20
p.133-162

The problem and opportunities associated with the use of biomass resources are sufficiently different from previous EPA missions that they present an opportunity for fresh innovative strategies with state and local government, the private sector, and the Federal agencies.

Regional impacts tend to be too big for local attention, and too small for EPA. Perhaps cooperative efforts could address the overall questions of regional impacts from biomass use, and out of these cooperative efforts a sharper definition of the roles of these dominant factors could be defined which would lead to effective local action via incentives, technical assistance, consensual standards, etc.

Nonpoint sources of pollution, both in relation to wood combustion and in growing and harvesting of the biomass materials, will emerge as the most important potential regulatory issues.

Although impacts can be projected and measured, new ideas are required to feed those insights back into mechanisms which can control the problem. One example is TVA's forest resource information system which can be used to alert harvesters to overcutting or to site new plants and procurement areas to prevent overcutting.

> We recommend that EPA again systematically reconsider its orientation toward biomass energy questions in terms of what comprises a national issue, a need for new and different kinds of interagency liaison and cooperation, the possibility and requirements for new outreach, and new kinds of organizational arrangements with the private sector.

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SECTION 2

INTRODUCTION

This is a planning study directed at identifying the research necessary to understand the long-term consequences on human health and safety, the biota, and the technoeconomy of a more extensive use of wood and other biomass for energy production in the United States.

Biomass, i.e., living or recently living material, currently supplies about 3% of the U. S. energy consumption. Current estimates of practical future contributions of biomass to U. S. energy needs by the year 2000 range from 6% - 15%. Some advocates cite an absolute limit of 20%, while others argue that contributions can, in the long run, be even greater.

As we enter the 1980's, three assumptions are widely accepted:

- The U. S. must use a mix of energy resources to meet its needs over the coming decades.
- Biomass sources of energy, while limited in their total potential contribution, will expand enough to have a significant role in the nation's economy.
- The regional consequences of shifts to biomass energy may be greater than the average consequences across the nation.

Some of the factors driving this expanding interest in biomass as an energy source are:

- the rising price of oil;
- concern over the stability of foreign sources of oil and gas;
- concern over the safety and future of nuclear power;
- concern over the environmental effects of increased use of coal and other fossil fuels (CO_2, strip mining, acid rain, mine safety, etc.);
- individual interest in energy self-sufficiency;
- the growing influence of the appropriate technology movement and the associated trend towards local self-sufficiency;
- the continued demand by the American people for improved environmental quality, including clean and safe energy;

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- the appeal of a renewable resource compared to the consumption of limited fossil fuels.

THE ENVIRONMENTAL AMBIENCE

As the nation's energy supply and use change, many major federal environmental programs and agencies will be mismatched with the new opportunities, problems, and issues. The Environmental Protection Agency, the Council on Environmental Quality, and the environmentally-oriented activities of the Department of Energy, the Department of the Interior and other departments reflect government's responses to the environmental problems prominent in the 1960's and early 1970's. These problems of air and water pollution, urban and rural solid waste, industial effluents, toxic materials, noise, and aesthetic insults are still with us as matters of continuing concern. While there has been significant progress, such as the building of a scientific base of understanding, these problems are not behind us.

Nevertheless, several big changes and a host of minor changes imply some reordering of the public agenda of environmental issues to accommodate new circumstances and new priorities.

- Increases in the price of energy and continuing dependence on foreign oil, while sufficient cause for concern, have stimulated continuing inflation which disrupts planning dependent upon a credible, solid future price structure of energy. Continuing price increases make alternatives to petroleum more attractive as we can see in the revival of coal. There is also the parallel concern of exploiting the individually smaller but collectively important alternative resources such as geothermal, tidal, and solar energy in all its protean forms.
- The new energy sources involve new technologies which imply different sources of concerns and unfamiliar problems.
- Shifting economics has brought many contenders into the game and raised great uncertainties as to which of them are likely to be among the winners.
- Complementing these practical technoeconomic considerations is a growing awareness that many of the problems prominent in the 60's and 70's arose from too weak foresight of side effects and the failure of business and government to take a broad enough view of our technological systems. Systematic anticipatory examination of our technological choices is increasingly acceptable to and desired by all stakeholders.

For all these reasons, there is growing concern about alternative energy sources.

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This biomass report concentrates on wood, which has many appealing features. People everywhere burn wood. Wood is renewable and has the appearance and the feel of being benign. Biomass, including wood, is a subject of a public advocacy program -- the solar energy lobby. Biomass is a mainstay of fuel for much of the Third and Fourth worlds. Unfortunately in those parts of the world, biomass is the subject of unequivocal environmental abuse, such as deforestation and long-term irreversible deterioration of the soil and the regional food, forest, and fibre base.

While in the U. S. wood and other biomass seem benign, desirable, cheap and self renewable, we must be cautious. This report deals with why we must be cautious and how we might exercise that caution.

History teaches us that almost every physical or biological technology had carried a regrettably large burden of negative, unintended, and unanticipated side effects. There is little reason to believe that burden will be any less from biomass energy.

The advocates of almost every new technology have emphasized its benefits and have been indifferent to, demeaned, discounted, or downplayed the negative consequences which have in principle been foreseeable. The chapter "Anticipating Future Environmental Problems" in EPA's Research Outlook 1980 documents this position by identifying eleven generic causes of environmental problems, and classifying them according to the extent to which the scope of the problem is understood.

EPA'S ROLE AND INTEREST IN BIOMASS

Should the use of biomass for energy expand severalfold, many new problems will arise which will involve new constituencies, call for new interagency relationships, and require innovative approaches to the resolution of issues, the solution of problems and maximization of public benefits. The subject of biomass is, of course, not new to EPA.

EPA has been involved with biomass sources of energy since 1970. Now the agency has the unusual opportunity to be a prime factor in the development of biomass energy as an environmentally positive technology. Rather than reacting to problems after they have developed, EPA can be an early, positive, formative force.

The principles of engineering design make it almost always less expensive to design a system to include all of the critical elements from the beginning. Any drastic retrofit after doubling, tripling, or quintupling biomass energy use would be unnecessarily expensive.

As an early stocktaking, this report attempts to identify the most important questions to be addressed in understanding the environmental implications and hence the research and policy implications of a systematic move to biomass.

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In its conceptual approach EPA is conspicuously generous in what it is attempting to map. The key areas of concerns are the effects of biomass on:

- human health and safety;
- the biota;
- the technoeconomy.

Two definitions may be helpful:

The biota include the earth, its plants, its animals, its soil, air, and water as media for living things except for those parts which are included under human health and safety or the technoeconomy.

The technoeconomy refers to the artifacts, laws, and physical and organizational processes of human culture. Thus we will consider commercially raised plants and animals as part of the technoeconomy rather than the biota. However, public parklands, endangered species, grasslands, crops, and front yard trees are all part of the biota.

THE STUDY STRATEGY AND FORMAT OF THIS REPORT

There is a vast literature on biomass. We have identified over a thousand publications and have every reason to believe we could double or triple that were we to go back to earlier times, broaden our search, and include foreign literature. Consequently, the strategy we have followed is to attempt to throw biomass technology into these perspectives:

- what is practical now and over the next generation -- the next twenty-five to thirty years;
- what are likely to be the main kinds of environmental consequences -- good, bad and uncertain -- of a substantial move to biomass.

Having told the story in these perspectives, the next objective is to identify key knowledge gaps and to relate those knowledge gaps to two things: knowledge needs in order to proceed with the technology in its human and environmental context, and knowledge needs to clarify current or latent public policy controversies. In other words, we wish to put useful information into the hands of technicians and policymakers.

Finally, we will focus on specific priorities for EPA's long-term engagement of this question.

No attempt will be made to trade off economic, environmental, or other objectives with other energy sources (e.g., biomass vs. geothermal-energy), but only to suggest the relative importance of objectives and consequences within the framework of biomass.

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Recognizing that the present federal structure with regard to health and the environment is framed around well recognized problems, the project also takes into account the lessons and implications for other agencies and levels of federal, state and local government.

THE AUDIENCE FOR THIS REPORT

A primary audience for this report are those responsible within EPA for planning research policy. It is assumed that many disparate areas are competing for high priority in the allocation of the Agency's resources. Consequently, the report focuses on major problems where research results could have a primary effect on decisions. It does not attempt or pretend to produce a detailed research program.

The report assumes that the primary audience will vary in knowledge of biomass. Consequently, the report has explicit elementary or introductory elements which are so marked and can be readily skipped over. For those less familiar with the subject the preliminary orientations may be useful.

The report further assumes that many of the most important new environmental issues will not comfortably fit within EPA or other agencies' charters. The question arises as to how to treat those jurisdictionally ambiguous items. We have tried to give them some attention without being presumptuous or arbitrary as to where they fit in the Federal establishment. We have attempted to identify the health, safety, and biological problems with regard to the issue at hand, but left it to those more intimately involved with the operations of government to determine where and how well or poorly they fit within the agency's charter.

By nature of the assignment and the budget, this project did not undertake any original field or laboratory research. It relies primarily upon an examination, collation, and analysis of the published research findings of others. A synthetic and critical examination of those reports is its contributions to the policy and research planning discussion. The report was strengthened by review and outreach to collect, correct, and organize its material and to critique its findings and recommendations.

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SECTION 3

BACKGROUND

PREVIEW

This section is background and context. The section sets wood in the context of biomass and in turn relates wood and other biomass to current energy consumption and production. It sorts out in a rough way the most likely candidates for practical large-scale use over the next decade or two.

Finally, the section treats trends, that is, long-term changes in the society which may influence the development and use of wood and other biomass.

Those readers already comfortable with this background material may choose to move directly to Section 4 on best estimates of future biomass energy use.

WHAT BIOMASS IS

Biomass is living or recently living material. It results directly or indirectly from sunlight (solar energy) converting water and carbon dioxide into plant substance. The plant may then be eaten and be converted into biomass directly or converted into animal waste -- manure.

The unique advantage of biomass as an energy source is that, despite the low efficiency of conversion of solar energy (usually about 0.2% to 2%), the process is self-renewing and can even occur without any technological or capital investment. Biomass is perhaps the most complex of the solar-based energy sources. Biomass energy in trees, crops, manure, seaweed, and algae can yield through conversion processes fuels to produce electricity, heat and steam, or to power vehicles. Some conversions also yield by-products for food, fertilizers, and chemicals.

BIOMASS AS A FORM OF SOLAR ENERGY

Most of the energy the world uses comes directly or indirectly from the sun. Exhibit 3-1 relates the total flow of solar energy to the earth to

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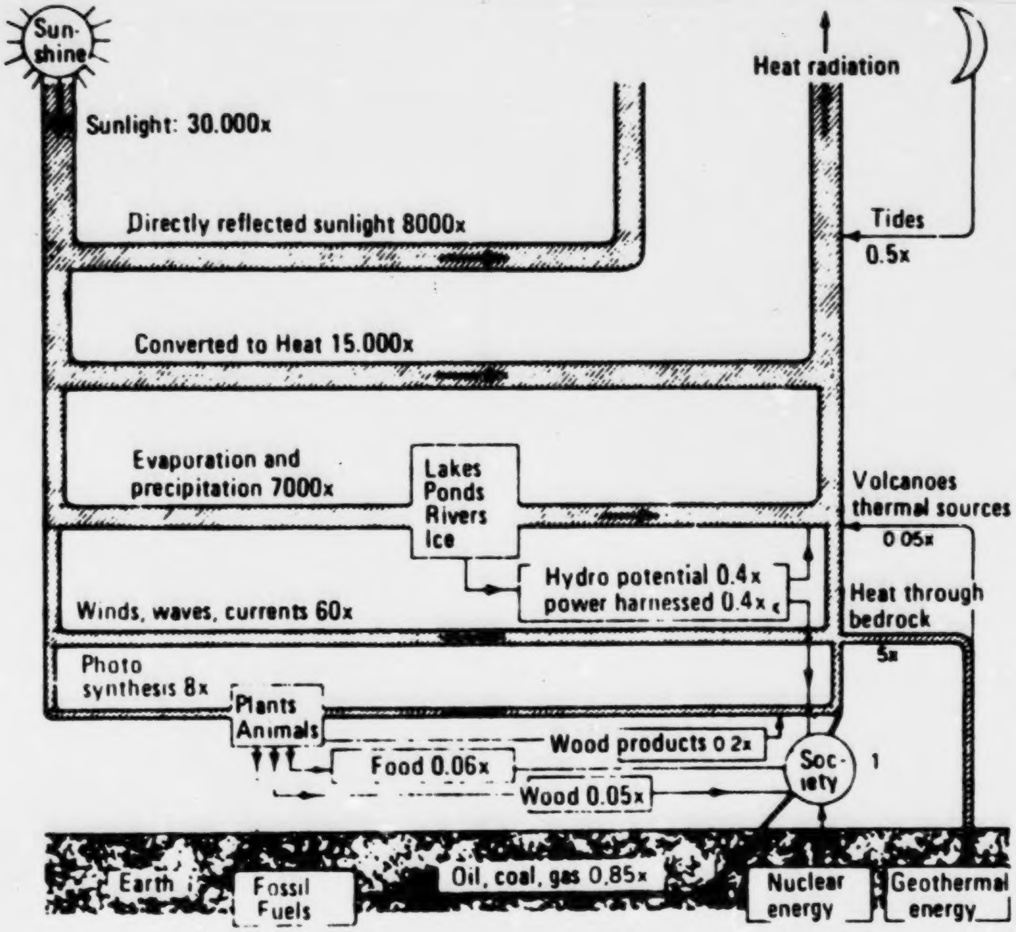
EXHIBIT 3-1

ENERGY FLOW ON EARTH


Sun-shine
Sunlight: 30.000x
Heat radiation
Directly reflected sunlight 8000x
Tides
0.5x
Converted to Heat 15.000x
Evaporation and precipitation 7000x
Lakes
Ponds
Rivers
Ice
Volcanoes thermal sources
0 05x
Hydro potential 0.4x
power harnessed 0.4x
Winds, waves, currents 60x
Heat through bedrock
5x
Photo synthesis 8x
Plants
Animals
Wood products 0 2x
Soc-iety
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Food 0.06x
Wood 0.05x
Earth
Fossil Fuels
Oil, coal, gas 0.85x
Nuclear energy
Geothermal energy

The energy flows are calculated in relation to the energy circulation in society, which has been set at one. Oil, coal and gas, for example, contribute 85% of the latter. That part of the solar energy radiation which is required to drive winds, waves and currents is 60 times as large, etc.

*Source: Mans Lonnroth et al, Solar Versus Nuclear (Oxford:Pergammon, 1980): page 5.

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that actually used for social purpose. If one takes the total amount used by society as a base unit of one, the amount of energy hitting the earth from the sun is 30,000 times greater. As the exhibit shows, one-fourth of that energy or 8,000 times the amount of energy used by society is immediately reflected back into space. Some 15,000 times society's energy use is converted into heat and then reradiated into space. Seven thousand times the amount used in society drives evaporation and precipitation leading to ponds, lakes, and rivers. From that a hydro-power potential is created equal to four-tenths of all of the energy used by society. The power actually harnessed is about one-tenth of that. Winds, waves, and ocean current energy equals 60 times the amount of energy used by society.

The photosynthetic potential -- the amount converted into plants and animals -- is equal to eight times the total energy consumption of society. When we actually get down to a close-in analysis of what is used, 85% of what is used does not come from the sun immediately, but comes from the long-term storage of solar energy mostly as oil, gas, and coal. Of all that energy captured by photosynthesis, eight times society's use, the amount converted into food equals 6% of our total societal consumption. The amount converted into wood for burning is equal to 5% of society's total consumption.

Numbers such as these engender the widespread enthusiasm for solar energy as a potential major contributor to the intermediate and long-range energy supplies of the United States. Obviously, this vast energy source is not as extensively used as some would wish because it is just not economically competitive with the oil, gas, and coal. That pattern is changing, but before we turn to the question of how much photosynthetic energy might be practically available in the next 10 to 30 years, let us consider what the overall pattern of energy use in the United States is now.

CURRENT ENERGY CONSUMPTION IN THE UNITED STATES

Exhibit 3-2 shows the energy consumption in the United States according to three different Department of Energy estimates since 1971. The difference of about 0.8 quads in the three estimates should alert the reader to avoid attaching too great significance to the accuracy of the numbers. Exhibit 3-3 shows the energy production within the United States since 1971. It is rather clear that production has been fairly stable at around 60 to 63 quads and consumption has continued to rise, the gap being made up by imported fuel, principally petroleum.

United States consumption for 1978 was by these figures 78 to 78.8 quads. A word of explanation on quads may be helpful. There are two common basic units of heat energy. The one that is most commonly used in engineering is called the British Thermal Unit (btu). A btu is that quantity of heat necessary to raise the temperature of one pound of water 1° Fahrenheit The quad is one quadrillion btu's. A quadrillion is one followed by 15 zeros. The energy unit "quad" is often written as 10^{15} btu's.

A more detailed history of energy consumption by primary energy type is shown in Exhibit 3-4 again, drawing upon the three different daily

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EXHIBIT 3-2
U. S. ENERGY CONSUMPTION *

Energy Consumption (EC)

	DOE[2]	DOE[1]	DOE[3]
	10^{15}		
1971	68.30		
1972	71.643	71.63	
1973	74.609	74.61	74.61
1974	72.759	72.76	72.76r
1975	70.707	70.71	70.71
1976	74.509	74.51	74.51r
1977	76.390	76.39	76.39r
1978	78.154	78.15	78.15r
1979	78.787	78.02p	78.02p

EXHIBIT 3-3
U. S. TOTAL ENERGY PRODUCTION *

	DOE[1]	DOE[2]	DOE[3]
	10^{15} Btu		
1971	61.70		
1972	62.81	62.805	
1973	62.43	62.433	62.43r
1974	61.23	61.229	61.23
1975	60.06	60.059	60.06
1976	60.09	60.090	60.09
1977	60.30	60.297	60.30r
1978	61.21	61.208	61.21r
1979p	62.80	63.537	62.80

p=preliminary
r=revised

1. DOE, Energy Information Administration Annual Report to Congress 1979, Vol. 2, DOE/EIA-0173(79)/2.

2. DOE, Monthly energy Review, August 1980.

3. DOE, Energy Data Report, Annual Energy Balance, 1979 (issued June 1980).

* Mensch, Harold L., Ed., Energy Statistics, vol. 3, number 3 (Technical Information Center, Institute of Gas Technology, Chicago, Illinois, Third Quarter 1980). p. 18 and p. 1.

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EXHIBIT 3-4: U.S. ENERGY CONSUMPTION BY PRIMARY ENERGY TYPE*

	Coal			Petroluem			Natural Gas-Dry		
	DOE[1]	DOE[2]	DOE[3]	DOE[1]	DOE[2]	DOE[3]	DOE[1]	DOE[2]	DOE[3]
	10^{15}								
1971		12.01			30.56			22.47	
1972	12.461	12.45		32.966	32.95		22.699	22.70	
1973	13.300	13.30	13.30	34.840	34.84	34.84	22.512	22.51	22.51
1974	12.876	12.88	12.88	33.455	33.45	33.45r	21.732	21.73	21.73
1975	12.823	12.82	12.82	32.731	32.73	32.73	19.948	19.95	19.95
1976	13.732	13.73	13.73	35.175	35.17	35.17r	20.345	20.35	20.35
1977	13.965	13.96	13.96r	37.176	37.18	37.18	19.931	19.93	19.93
1978	13.846	13.85	13.85r	37.965	37.97	37.97r	20.000	20.00	20.00r
1979	15.040	15.08p	15.08p	37.135	37.02	37.02p	20.546	19.86	19.86p

	Electricity											
	Hydro			Nuclear			Geothermal and Other 4		Geothermal	Wood and Waste	Net Imports of Coal Coke	
	DOE[1]	DOE[2]	DOE[3]	DOE[1]	DOE[2]	DOE[3]	DOE[1]	DOE[3]	DOE[2]	DOE[2]	DOE[1]	DOE[2]
	10^{15} Btu											
1971		2.86			0.41				0.01	0.005		(0.03)
1972	2.929	2.94		0.577	0.58		0.011		0.03	0.005		(0.03)
1973	3.010	3.01	3.01	0.910	0.91	0.91	0.046	0.05	0.04	0.005	(0.008)	(0.01)
1974	3.309	3.31	3.31	1.272	1.27	1.27	0.056	0.06	0.05	0.005	0.059	0.06
1975	3.219	3.22	3.22	1.900	1.90	1.90	0.072	0.07	0.07	0.005	0.014	0.01
1976	3.066	3.07	3.07	2.111	2.11	2.11	0.081	0.08	0.08	0.005	0.000	0.005
1977	2.519	2.52	2.52	2.702	2.70	2.70	0.082	0.08	0.08	0.01	0.015	0.02
1978	3.168	3.17	3.17r	2.977	2.98	2.98	0.068	0.07	0.06	0	0.131	0.13
1979	3.163	3.16p	3.16p	2.748	2.75p	2.75p	0.089	0.09p	0.08p	0.01p	0.066	0.07p

p = preliminary
r = revised

1. DOE, Monthly Energy Review, August 1980

2. DOE, Energy Information Administration Annual Report to Congress 1979, Vol. 2, DOE/EIA-0173(79)/2.

3. DOE, Energy Data Report, Annual Energy Balance, 1979 (issued June 1980).

4. Other includes electricity produced from wood and waste, and net imports of coke.

* Mensch, Harold L., Ed., Energy Statistics, vol. 3, number 3 (Technical Information Center, Institute of Gas Technology, Chicago, Illinois, Third Quarter 1980), p. 17.

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estimates as assembled by the Institute of Gas Technology in Chicago. Those particular tallies put wood and waste as at very low values of essentially 0.1 quads of energy consumption (1).

The evidence is strong that biomass and other organic waste provide far in excess of 0.1 quads of energy.

- A recently completed study of energy from biomass by the Mitre Corporation estimates that 2% of the nation's 1980 energy resulted from biomass, primarily wood burned by industry and home owners (2).
- More detailed attention to wood and other biomass energy consumption in Paul Bente of the Bio-energy Council suggests that bio-energy, nearly all of which is from wood waste, is equal to about 3% of total energy use (3).
- A June-July 1979 survey by the Gallup organization put domestic fuel wood consumption at 50 million cords, or approximately 0.85 quads (4).

It would, therefore, be more realistic to assume that the 1979 annual consumption of energy was closer to 80 quads. Exhibit 3-5 presents the distribution of that U. S. energy consumption, drawing upon the data in Exhibits 3-2, 3-3, 3-4 and the above data. The reason for a relative underestimation of biomass consumption has to do with the fact that a great amount of it is often internally consumed by the wood products industry. Other large quantities are directly consumed by home owners buying wood through informal channels and small business operations, or used directly on farms and rural areas which use is difficult to assay. The data as presented in Exhibit 3-5 suggest, however, that renewable biomass energy is becoming comparable to nuclear power and far exceeds geothermal power and is even approaching hydropower as a substantial contributor to the current energy picture. The relatively obscure nature of biomass energy, however, is interestingly reflected in a recent Joint Economic Committee report to the Congress on energy supply options, cost effectiveness, and R&D strategies. Wood energy was not discussed (5).

In summary, renewable biomass is a small contributor to the current energy consumption -- but it is an enormous natural resource awaiting further use.

Before turning to the likely contribution of biomass to our overall energy balance, it is useful to more explicitly define eight major sources of biomass in the United States.

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EXHIBIT 3-5

U. S. ENERGY CONSUMPTION, 1978

A

INTERNAL ENERGY

GEOTHERMAL	0.09
NUCLEAR	2.75
GRAVITATION (TIDAL)	0
TOTAL	2.84 Quads

B

SOLAR ENERGY

DIRECT HEATING	
PHYSICAL	
SHORT-TERM	
Wind	0
LONG-TERM	
Hydro	3.16
Ocean Current/Temp	0
BIOMASS	
RENEWABLE WOOD & WASTE	2.4
LONG-TERM	
Peat	0
VERY LONG-TERM	
Coal	15.04
Oil	37.14
Natural Gas	20.54
TOTAL	78.28
A & B =	81.1

The Energy Number
80 Quads

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EIGHT KINDS OF BIOMASS RESOURCES

Biomass is by no means limited to biological materials produced on land. While the classification is still somewhat arbitrary, there are eight widely recognized categories of biomass, several of which are outside the scope of this report.

The dominant emphasis in this report will be on trees and forest residues with much less attention to plants, woody and non-woody other than trees, crops, and crop residues and animal and processing wastes. The three areas covered are:

Wood

This category includes trees grown specifically as a fuelstock, as well as wastes of the lumbering and wood processing industry. Wood is found in small dispersed wood lots on private and public lands, in forests, and in wildlife preserves and parks.

Wood is not a static resource. Scientific, economic, and managerial developments can make it into a new economic growth sector.

Non-Wood Plants

This category includes conventional and unconventional crops, agricultural wastes and byproducts, and grasses.

Animal Byproducts and Wastes, and Food, and Fibre Processing Wastes

This category includes manures and other animal and food byproduct wastes such as cheese whey, cotton gin wastes, and peanut shells which result from the food processing industries.

The following five sources will not be covered in this report although references are given for those who wish to follow up on them:

Aquatic Plants

This includes vascular and nonvascular freshwater and marine plants. Freshwater candidates currently being discussed for aquaculture and energy harvesting include the water hyacinth (6). Candidacy in the marine environment has generally focused on the giant kelp, Macrocycstis spp (7).

Marine plants, while potentially of enormous significance, will not be covered, since these technologies are years to decades in the future. The opportunity for exploitation of terrestrial biomass is more immediate, more unequivocal, has fewer technological obstacles, and will have a bigger short-term payoff.

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The interest in fresh water plants for biomass energy has quite different origins. First, rapidly growing vascular aquatic plants are an increasingly serious nuisance here and abroad. Some grow at phenomenal rates. Azolla, one prolific weed, doubles its weight in a week. Second, some plants such as water hyancinths are very useful in "polishing" water from secondary sewage treatment. Water hyacinths also concentrate toxic or undesirable trace materials helping to purify the water. Third, semi-aquatic plants like cattails, growing in wet terrain are prolific, rapid-growing plants. There is no little doubt that this kind of vegetation can be harvested and provide a source of biogas.

The combination of the removal of a serious nuisance weed, the potential for some environmental cleanup, and the convertibility of this material into a more usable energy from biogas merits some attention. Aquatic plant use, however, is likely under any circumstances to be on a small scale and to be tied to other environmental objectives, e.g., cleanup of fresh water bodies or as an adjunct to sewage treatment.

Urban Refuse

Paper, construction scrap, food waste, and sewage sludge are often characterized as biomass feedstock. They have received considerable attention from public institutions concerned with urban solid waste and sludge management. As both issues and opportunities, these materials are well understood. Therefore, they will not be addressed in this report except as incidental to wood, agricultural, or aquatic biomass resources.

There are about 10 quads of biomass energy in various municipal dumps. There is a substantial amount of biomass, about 3.2 quads, in what is called short-term storage in the form of scrap paper and other biologically based municipal wastes.

Peat (8)

The U. S. has the world's third largest peat deposits -- over 50 million acres, the calculated equivalent of 240 billion barrels of oil. Alaska, Minnesota, Michigan, and Florida have large reserves. Russia, with the world's largest supply, fuels a hundred power plants on peat alone.

Peat is a renewable resource, although it has a long turnover time. Peat bogs are the accumulated products of the decomposition of reeds and mosses (especially *Sphagnum* moss) in still or stagnant waters. Atmospheric oxidation and anaerobic action of bacteria, yeast, and fungi combine to produce detritus which settles in the pools of water and, with time and under pressure of added deposits, partially carbonizes to form peat. Natural ongoing decomposition in peat bogs releases marsh gas, or methane.

The renewal time, the technologies and the economics of the use of peat do not fit the theme of this report.

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Hydrogen Producing Plants (9)

This is a long-term possibility now at the research stage. Biophotolysis involves the direct production of hydrogen by photosynthesis, using specific types of known hydrogen-producing algae. Research is underway concerning two different ways to increase the amount of hydrogen produced. One is to encourage photosynthetic growth in a species of algae, and simultaneously to alter the reaction conditions so as to maximize hydrogen production in situ. The second is to isolate the key chemicals and enzymes involved in the process and then generate hydrogen via a controlled synthetic reaction. Biophotolysis is now at the early research stage and is not a topic meriting further consideration in this report.

Plants Fluids (10)

These include hydrocarbons, vegetable oils, and oleoresins. Developments in plant genetics and the potential for new harvesting and crop management techniques imply that plant fluid fuels merit attention as new sources. Their energy impacts may be direct insofar as liquid fuels substitute for gasoline or diesel oil. One semi-tropical plant produces a fuel which can be directly used in diesel engines. Euphorbia, the gopher plant, produces up to 25 barrels of crude oil per hectare. Others also emit a direct substitute for diesel oil. Jojoba emits a lubricant, Botrycoccus braurii, a unicellular algae produces up to 75% of its dry weight in a hydrocarbon oil. Most of these are native to a tropical climate. Sunflower oil and peanut oil can also fuel diesel engines.

No analyst has any clear and credible idea of the short- or intermediate-range potential of these plants as contributors to our energy supply, but the notion of extracting liquids from plants for fuel purposes is extremely promising for research and development.

Since the purpose of this study is to provide guidance to EPA on practical research issues applicable to biomass energy, we judge that plant fuels, as with the other potential biomass energy sources not covered in this report, are not practical contenders for extensive development in the next decade or so. Furthermore, should developments make these alternatives sharply attractive or suddenly modify their technical-economic feasibility there should be ample time to study and evaluate their environmental effects.

OTHER LIMITATIONS ON THIS REPORT

First, since EPA has a separate study underway on ethyl alcohol as fuel from biomass, it is excluded from this report. Specifically excluded in discussion is ethyl alcohol, from crops and grain, or other fermentation processes leading to gasohol.

Second, we avoid the economics of inter-fuel competition of biomass, which are uncertain and in rapid flux. Furthermore, government policy -- as it always has with energy and other resources -- has a strong influence in creating incentives and disincentives to use biomass. It is our belief that

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should biomass in the long term become a factor of major importance to our net energy consumption, the macro-economics of its use will have little influence on environmental effects. Ignoring economics is also appropriate, since the transition problems in the growing use of biomass are outside the scope of this study. This report deals with the long-term environmental effects of a massive increase in the use of biomass by the year 2000.

National, regional and local economics will affect the distribution in the use of biomass. Among the important factors at the local and regional levels are:

- the availability and cost of collecting and distributing the fuel,
- the end use, of direct combustion, conversion to liquid fuel, etc.,
- the scale of use,
- the importance of renewability,
- the importance of assured supply,
- necessary environmental pollution controls, and other environmental problems.

In addition to the microeconomic factors above, the great uncertainties about inter-fuel price competition and the alternative strategies available for conservation, other factors confound the estimation of practical limits on biomass energy resources.

Most of these have to do with balancing short-term production economics with potential optimum production under extensive long-term management. More specifically:

- Steady state levels, at which production could be maintained from a cost and energy effectiveness point of view are unknown for any plant or tree crops. It should be noted, however, that in the South where forest cultivation has been going on for decades, as many as five generations of crops have been grown and harvested under cultivation.
- Inflation in the cost of oil and fossil fuels will promote biomass as a lower cost competitor. The rising price of other energy sources will also make what is now marginal more attractive.
- The consequences of unprecedented intervention -- such as improved genetic manipulation, improved processes for planting, nurturing and harvesting -- are uncertain.
- The economic realities of harvesting, moving, and using the energy source are in flux -- obviously a tree on a peak of the High Sierras has far lower economic value than the equivalent cut wood adjacent

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to your fireplace.

- Competing uses of land and the supporting resources may set limits to expansion and put biomass for energy in competition with alternative land uses.
- Fertilizer costs, pesticide costs, and general costs of fossil fuels will probably cause family farms, and perhaps later industrial farms, to move toward a greater degree of self-sufficiency and greater employment of available resources as substitutes for commercial fuel. Furthermore, constraints on the use of pesticides may lead to new cultivation practices, making the use of natural materials more economically attractive.
- Water supply may turn out to be a limitation on both vegetative and woody biomass energy. Since all plants require some water, the regional competition for water is becoming increasingly complex. The complexity involves exports and imports of water from basins, the allocation of water for urban development, for agriculture and possibly now for forestry. One might anticipate that in general the current economics of water that favor crops for food will prevail over water for other applications.
- Growing public concern about the natural environment has led to a widespread enthusiasm and positive attitude toward biologically produced materials.
- The appropriate technology movement -- with larger numbers of people seeking self-sufficiency -- will be a strong driver toward the low and intermediate level use of biomass.

A number of anticipated if not impending scientific and technological breakthroughs would make the use of biomass more attractive. For example:

- a more energetically dense tree (less moisture, more rapid growth);
- improved crop plants, from the perspective of requiring less water and having more rapid growth;
- enzyme technology affecting the direct conversion of woody plants to alcohol;
- a breakthrough in the biochemistry and genetics of photosynthesis, leading to improved conversions of sunlight into mass;
- intermediate and long-range implications of developments of aquatic plants, hydrogen producing plants, and plant fluids are so scientifically, technologically, economically, and ecologically uncertain as to keep the game wide open over the next several decades.

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SOME GENETICS CONSIDERATIONS

As long as people have engaged in agriculture and animal husbandry the genetic manipulation of plant and animal stocks has been a conscious part of the farmer's attempt to improve his production. The development of the formal science of genetics the end of the last century gave more effective and systematic tools for the manipulation, control, propagation and management of crops and animals. Most recently the development of modern genetics premised around an understanding of and the ability to manipulate the fundamental genetic materials, DNA, is opening up new opportunities to intervene in vegetative and woody plants, with an unprecedented degree of effectiveness and control. Among the possibilities which one sees influencing the development of plants for bioenergetic purposes are (11, 12):

1. The development of in vitro techniques for mass propagation (clonal propagation) of trees and other plant species. In vitro techniques can enormously accelerate the propagation of a desirable type since they do not depend upon the plant growing to maturity in order to propagate. Clonal propagation can also have the advantage over conventional propagation in uniformity and superiority of the resulting organism.

2. Advances in direct manipulation of nitrogen fixing bacteria, either free-living organisms or symbiotic with other organisms, may have a dramatic effect on the demand for fertilizer. The application of this technology to trees seems to be well behind the attempts to apply it to food crops. But in the long pull many of the nutrient problems associated with silviculture may be dealt with or greatly relieved genetically.

3. The development of plants which are resistant to disease, pests, etc., is almost certain to come to pass in all commercial plant species. The extent to which that resistance is effective and not thwarted by evolution among the disease organisms and the pest species is, of course, an open question. There seem to be few opportunities for growth of absolutely resistant organisms. But the ability to develop and propagate varieties rapidly gives mankind a new edge in this constant struggle between host and pest.

4. Development of plants which can grow on marginal lands, e.g., which may be salt tolerant, heavy metal tolerant, have less demand for water, and so on is well within the range of expectations of genetic manipulation through modern techniques.

5. The transfer of genes within and between species through recombinant techniques opens up the possibility of combining desirable characteristics from different organisms at a pace and effectiveness that is unprecedented.

Most of the current R&D on an application of genetics to plant species is concentrating on food crops. The application to biomass crops such as

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kelp and hydrogen producing plants seems farther down the road. On the other hand, the application to plants producing liquid fuels may be of more immediate interest.

Certainly the big short-term pay-off in biomass is the application of these modern techniques to trees.

It may be desirable and appropriate for EPA jointly with the Forest Service and Department of Energy to hold a specific research planning conference on the application of modern genetics to biomass application, particularly in the trees and other wood crops. Such a conference and workshop might provide a useful division of labor, a long-term focus, and the ability to define research done best in private sector laboratories.

The risk of genetically homogeneous crops, so-called mono-cultures, to epidemics, predators, pest, etc., is well known. The use of modern genetic techniques to produce vegetative and woody crops with relatively uniform commercially desirable properties may undercut the risks of traditional monoculture crops in several ways. The growth time of tree crops, for example, may be substantially reduced through genetic improvement. Furthermore, the clonal propagation of new varieties resistant to any pest which may arise can be brought about at a rapid pace, a pace which may be virtually coincident with the development, propagation, and recognition of the new pest.

TRENDS INFLUENCING THE USE OF BIOMASS ENERGY

One approach to understanding the societal context of an expanding use of biomass is in terms of trends influencing its use. Trends are a key to identifying the social context and a clue to indicators of expanding or declining interest in a technology.

Trend 1 - Inflation

The continued, and we presume irreversible, increase in the price of petroleum is a most significant economic development in the United States and the rest of the world. As the relative cost of all fuels go up, the relative appeal of biomass will increase as an alternative for coping with the petroleum price rise. The cost of biomass will also increase, but probably at a slower rate, making it an increasingly attractive alternative until its price rises catch up and come into equilibrium with other fuel alternatives. A derivative trend is an awareness of a need to reduce foreign oil dependency. This again increases the appeal of all alternatives to petroleum, including biomass. That appeal, of course, is not likely to be reduced to effective corporate or individual practice without specific policy actions directed at reducing foreign oil dependency and increasing the use of many alternatives.

Inflation will drive home owners to search for alternative means of home heating. This is evidenced by the increased use of wood for residential

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fireplaces, stoves, and to some extent, for central heating. The inflation driven shift is reflected by the number of studies on a state and regional basis, e.g., New York, Georgia, Michigan, North Carolina, Vermont, and California, on the use of biomass (13).

Trend 2 - Decline in Consumption of Conventional Fuels

As the relative cost of all fuels go up, the consumption of petroleum fuels and other fossil fuels will decrease. Hence, the relative importance of biomass will increase. Within the last several years, better knowledge of the price elasticity of demand of gasoline and household fuel has developed. There can be little doubt now that energy consumption is price responsive. Consequently, as the growth in energy demand falls off, the relative importance of biomass will increase. Specifically, if total energy demand remained at 80 quads between now and the turn of the century, and biomass production increased to 5 or 15 quads respectively, the percent of biomass would increase from its present 3% to 6.25%, or to 18.75%, of all energy used.

Trend 3 - Changing Migration Patterns

The past decade has seen a slight but undeniable reversal in the long-term pattern of urbanization. The trend in migration to rural counties on the metropolitan fringe is quite real. This real increase may be reflective of a national movement toward independence, autonomy, improved quality of life, a general sense of small being beautiful, a movement toward do-it-yourself, appropriate technology and new social behaviors. Therefore, the rural migration and the repopulation of the countryside provide a bigger labor base and the demand for new and alternative energy sources. Innovation often comes with outsiders.

Trend 4 - Value Changes

As mentioned earlier, implicit in the above arguments for the causes behind the rural migration is a general change in attitude toward material goods. Higher quality goods are sought even at the expense of less quantity. There is a greater respect for the balance of nature, an awareness of ecological concerns, and the sense of the need to conserve resources. Going along with that is the growth of the service sector, and a new movement rivaling that of the post World War II do-it-yourself boom. All of these make the labor intensivity associated with some uses of biomass, such as residential heating, both practical and attractive.

Trend 5 - Diversification of Oil Companies into Other Energy Sources

The movement of large oil companies into non-petroleum energy sources would bring a substantial infusion of capital, high technology skills, and a sophisticated research and development base to biomass. While the current interest of the oil companies in biomass seems to be limited to research monitoring and exploratory planning, oil companies are becoming more comfortable with unconventional forms of research, such as genetic

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manipulation. One might see this oil company tendency toward diversification as reasonably likely to move them into biomass. These technologies will cover the gamut from forest management to genetic manipulation. One might see this oil company tendency toward diversification as reasonably likely to move them into biomass. These technologies will cover the gamut from forest management to genetic manipulation. One can anticipate that this interest by the relatively cash-rich, achievement-oriented oil companies could go a long way toward testing and probing the various technological and management alternatives for biomass.

Trend 6 - Science and Technology

A series of major development areas have the potential to form a new basis for biomass exploitation. In addition to genetic manipulation which has already been discussed, these new bases include:

- telematics -- the combination of telecommunications and computer information technologies;
- ecology;
- technologies of forestry;
- cultural treatment.

Telematics. Traditional farms, particularly those in the Midwest, are vigorously acquiring micro-computers as aids to farm management. In some areas the monitoring of cows with micro-processors has permitted milk yields to jump from average production of 12,000 pounds up to as much as 22,000 pounds per cow per year. The invasion of the farm by telecommunications technology will affect every level of rural operation. One illustration may be that the micro-processor when applied to biogas technologies may help overcome two of the clear obstacles to more widespread use: the economics and the inconvenience of frequent attention to the generator.

Computers are being used in a number of interesting ways in forestry. Models of individual tree stems and the ability therefrom to simulate buckling patterns by computer has led to the development of the so-called Improved Harvesting Program (IHP) of the Forest Service-USDA. John F. White of the Forest Service reports a national potential improvement in yields of 4 to 6% in logging through this technique (14). Computers have also been used to improve decison-making in the selection of small logs for processing in the sawmill. A computer simulation program developed in the Forest Products Laboratory in Madison, Wisconsin, has been the basis for substantial technological changes in sawmilling and has resulted in a maximum lumber yield from logs after they have been scanned and located on the processing equipment. (15)

Ecology. Ecology is slowly and steadily moving to a more practically oriented and more quantitatively grounded science. While we see that

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great progress has yet to be made, the science is on the move and the knowledge base is growing (16). The current status of ecological knowledge and its ability to provide practical guidance in forest management are discussed in greater length in the chapters on wood below.

Technology of Forestry. The technology of forestry is growing at a quite rapid rate as noted elsewhere. Technological intensivity may offer the opportunity to change the basic economic structure of wood harvesting. Forest management technology is discussed in greater detail in the chapters on wood.

Trend 7 - International Markets

Attractive international markets for wood fuel potentially exist, particularly dependent upon pelletization and densification technologies. The opportunity to deliver wood to Third World ports facing raw wood shortages may represent both a major market and a major international innovation by relieving a shortage of a traditional local fuel source. A point to note is that in the last century Yankee clippers delivered New England ice by schooner to China and Australia.

Trend 8 - Public Concerns

Concerns over the use of wood for energy will rise significantly as wood plays a larger role in meeting total energy needs. The transition from a relatively unmanaged forest situation to an intensively managed situation will not be smooth. Much of the forest biomass harvested for energy purposes over the next decade or so may come from non-industrial private buildings. A general lack of knowledge of scientific forest management principles, high rates of inflation, estate taxation, and *ad valorem* property taxation reduce incentives to manage and harvest properly. Examples of poor harvesting practices may increase. Because of the relative cost advantages, harvesting for firewood will be particularly common near population concentrations where improper harvesting is particularly visible. In the longer run, large-scale conversion of forest land to intensively cultured energy plantations will raise some concerns similar to those raised by conversion of sites to pine plantations for pulp and paper production. These concerns revolve around the issue of ecological diversity, and the importance of such diversity for wildlife management and for high quality outdoor recreations.

Trend 9 - Improved Monitoring

Increases in monitoring capability will unfold at both the macro- and the micro-site levels. Satellite-based remote sensing technology will be increasingly used to monitor changes in land use associated with biomass utilization. Experience with micro-processor and microcomputer applications in agriculture will be extended to sites used for producing other biomass. Intensive monitoring of growth, yield, nutrient changes and other key factors will be regularly monitored.

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Trend 10 - Trends in Wood Use

There are big uncertainties in the future of conventional uses of wood. Within the United States a long-term decline in wood use may be associated with the decline in housing starts. Some see this as only a temporary setback. A second trend driving wood use down may be the displacement of paper by telematics technology. While telecommunication and computer technology increase paper use in the office in the short term, the overall effect on paper may be quite different as we become more telecommunications intensive. The growth of two-way cable, computers, and so on may displace such major users as newspapers, catalogs, magazines, and cheap paperback publications. This is much too uncertain to represent anything more than an opportunity for monitoring.

Trend 11 - Federal Policy

The "National Plan for Energy Development and Demonstration: Creating Energy Choices for the Future" was published in 1975 by the Energy Research and Development Administration as ERDA 48; it identified three objectives: a near-term, a mid-term, and a long-term.

Objectives

Near-Term (-1985):	To investigate the economic and technical feasibility of production of terrestrial plant biomass and the conversion of these organic materials including agricultural and forest residues to useful clean fuels, thus providing the technology which, if implemented by industry, would have the potential for producing approximately 0.2 to 1.0 Quads per year.
Mid-Term (-2000):	To investigate the economic and technical feasibility of producing marine biomass and converting these organic materials to clean fuels, petrochemical substitutes and food, thus providing the technology base which, if implemented by industry, would have the potential for producing approximately 2 to 5 Quads per year of fuels and industrial chemicals from both terrestrial and marine sources by 2000.
Long-Term (+2000):	To improve biomass yields and conversion efficiencies, and provide the necessary technological basis for greater commercialization with a potential for production ranging from 10 to 30 Quads per year of fuels and petrochemical substitutes from terrestrial and marine sources by 2020.

It is rather clear that the 1985 objective has already been met by naturally unfolding events. The objective was to have 0.2 to 1.0 quads per year of

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biomass in use. The data already discussed suggests substantially more than that is used now.

While it is national policy to reduce dependency on foreign oil and hence, by implication national policy to use alternative resources, such as coal and biomass, the microeconomics are not necessarily attentive to or responsive to national policy statements. At any particular location the microeconomics would drive the decision to wood, to coal, to nuclear, or to some other alternative. While it would be rash to speculate as to what the general pattern of those microeconomic trade-offs might be, technological and economic certainty, familiarity with processes, assurance of supply of fuel and so on now might work to create a strong bias in favor of coal. If it is in the national interest to promote biomass energy as fuel, we probably will need much more explicit policy implementation to correct any bias in the microeconomics favoring one fuel over another or even in fact to stimulate the microeconomics to favor one fuel over another. Details of those arguments are outside the scope of this report. More important than the question of the technical merits of coal over biomass, or biomass over nuclear power, is the need for policy-makers to recognize that the new technology, biomass. is at an economic disadvantage in almost all situations over a well-established and familiar technology and raw material with a good supply system. There is a need for policy discussion and possibly for policy actions based on those discussions to determine whether action should be taken to promote biomass over other fuels in those regions where it is otherwise technically, economically, and environmentally practical.

According to a quite comprehensive study by the Congressional Office of Technology Assessment, there are three key policy issues that the Congress must address if the United States is to move to the potential of 12 to 17 quads per year by the year 2000 (a production level estimated practice in that same report). The policy issues are (17):

- Economic incentives are needed to accelerate bioenergy development; and to lead to the establishment of the necessary infrastructure;

- The incentives for biomass development should include provisions for periodic review and adjustment in view of the limited knowledge, the unresolved questions, and the interconnectedness of markets for the biomass base;

- The priority of biomass should be raised in the Departments of Energy and Agriculture.

In summary, these dozen trend areas and perhaps a dozen more will influence the development of biomass. No trend area seems dominant or certain and hence the future of biomass is itself uncertain.

Let us turn now to some best estimates of the future potential of biomass in the United States.

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SECTION 4

FORECASTING BIOMASS ENERGY USE

PREVIEW

The chapter briefly looks at long-range energy forecasts to make a point, the forecast of energy from biomass based on overall energy use patterns is chancy. The analysis of the impacts of biomass must be based more to the consequences of plausible assumptions of how large increases in its use could be, rather than on projecting what those increases may be. The argument is parametric -- an argument in the terms of boundary conditions and practical judgment of events within those boundaries.

The second half of this chapter reviews recent systematic treatments of the potential for biomass energy over the next twenty to thirty years. On that basis, it concludes that in order of total contributions to the nation's net practical energy utilization, the significant candidates are wood and forest waste, agricultural waste, food waste, and manure.

INTRODUCTION

To forecast a reasonable and useful range of use of biomass as an energy source over the next several decades. one would normally expect to rely upon solid background forecasts of overall energy demand and supply. Against that background one would begin to forecast the alternative market penetration futures for biomass energy. The latter forecasts would be based upon technical and economic considerations and assumptions about stable public policies.

Unfortunately, none of these desirable conditions exist to permit reliable forecast of aggregate biomass demand. The next part of this section reviews the limitations on energy forecasts as guidelines to overall energy consumption in the next several decades. The following subsection relates biomass to overall movement toward energy conservation and highlights the fact that even the relative role of biomass in overall energy supply and demand is difficult to conjecture. The third subsection summarizes and integrates a number of points of view on the ultimate potential contribution of biomass to our overall energy balance. It comes to what we take to be commonsense conclusion with strong consensus from a number of analyses that the most significant biomass energy source for the next decade is wood, with crop waste as the supporting source. Other sources are sorted out and discussed in that section.

WHAT DO ENERGY FORECASTS TELL US ABOUT BIOMASS USE?

There has been a ten-year trend in global and U.S. energy forecasts to

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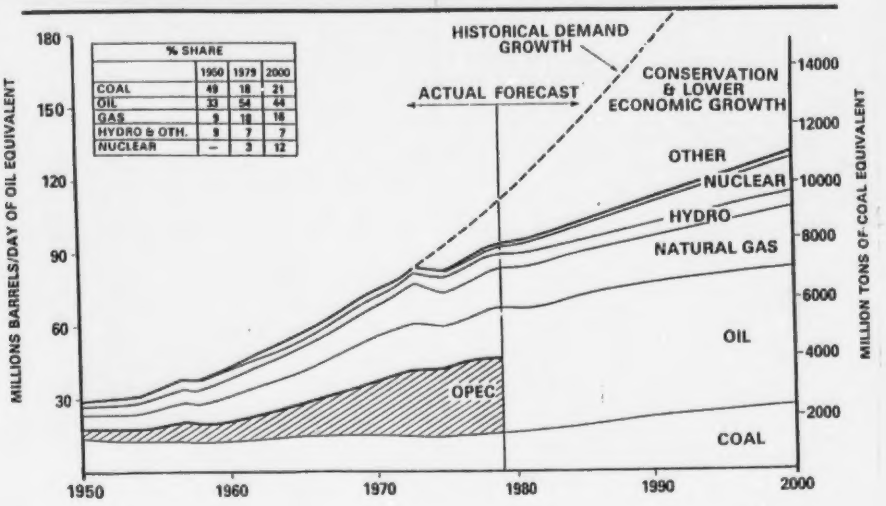
increasingly emphasize the importance of solar energy in general and biomass in particular.

The forecasting data on a global basis is illustrated in Exhibit 4-1 from C.W. Daniels, President of Shell Canada. The so-called "historical demand growth" is virtually a mechanical extrapolation of the patterns from the 1950's through the 1970's. The OPEC oil embargo caused a kink in the demand curve. Currently the world's primary energy demand suggests that growth will have an entirely different pattern from that seen in 1970.

EXHIBIT 4-1: WORLD PRIMARY ENERGY DEMAND (Excluding the Communist Areas)



*Source: C.Wm. Daniel, President Shell Canada.

The U.S. situation and the dramatic changes in energy forecasts are illustrated in the 1972 diagram (Exhibit 4-2) from Earl Cook, a well regarded energy specialist and forecaster. In that exhibit, which had 1972 energy consumption in the neighborhood of 60 quads, the basic long-term forecast was that by the year 2000 consumption would jump to somewhere around 160 quads. This was premised around continuing per capita energy consumption leveling off after the year 2000. Continuing population growth would cause the aggregate demand to rise. Cook, along with other analysts in government, industry, and the private research organizations, saw a decline in oil and natural gas consumption and short-term growth in tar sands and oil shale, and a substantial growth in coal. The use of Uranium 235 in his forecast would peak in the middle of the next century and then decline, to be replaced by solar energy, fast breeder reactors, and a substantial continuing contribution from coal. Cook's picture is contradicted by virtually all evidence and forecasts since then.

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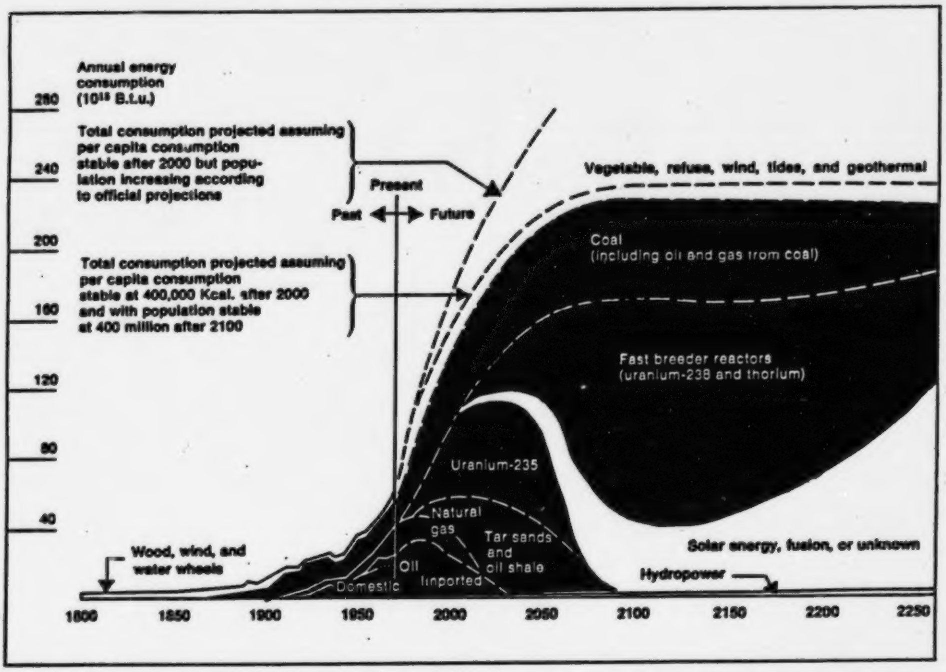
EXHIBIT 4-2: COOK'S 1972 ENERGY FORECAST*



What does the future hold for U.S. energy consumption—and the sources whence it comes? This proposal projects consumption under two different population conditions—and shows for a stabilized population how energy needs might be met into the third millenium. Energy will surely become more expensive, but—at least through the year 2250—it will still be available. This stable-population assumption produces a plateau of about four times the present rate of energy consumption.

*Source: Earl Cook, Technology Review. (December, 1972), p.23.

THE PATTERN OF LONG-RANGE FORECAST FROM 1972-1978

Amory Lovins has conveniently summarized the patterns of long-term energy forecasts from 1972 to 1978 (Exhibit 4-3). In Lovin's table -- the conventional wisdom reflecting arguments much like Cook's -- the Atomic Energy Commission forecasts saw a jump in energy consumption by the turn of the century to about 160 quads. The super-enthusiasts for energy growth -- tied to the industry and conveniently represented by the Federal Power Commission -- in 1972 saw consumption by the year 2000 as high as 90 quads. Heretical or conservative views -- represented by the Sierra Club -- saw growth to only 140 quads. In contrast, Lovins, a leading edge of a radical perspective of the future of energy, saw growth leveling off at about 125 quads.

Forced by OPEC's international disruption, the cross-fertilization of knowledge, the steady refinement of analyses, the questioning of underlying assumptions, and repeated independent and quasi-independent studies have led to a long-term general decline in the quads forecast for the turn of the milenium. Today, the most extreme enthusiasts for energy growth accept Lovins'

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EXHIBIT 4-3: THE 8 YEAR PATTERN OF ENERGY FORECASTS

Year of Forecast	Beyond the Pale	Heresy	Conventional Wisdom	Superstition
1972	125* (Lovins)	140 (Sierra)	160 (AEC)	190 (FPC)
1974	100 (Ford zeg)	124 (Ford tf)	140 (ERDA)	160 (EEI)
1976	75 (Lovins)	89-95 (Von Hippel)	124 (ERDA)	140 (EEI)
1977-78	33 (Steinhart)	67-77 (NAS1, 11)	96-101 (NAS 111, AW)	124 (Lapp)

Abbreviations: Sierra, Sierra Club; AEC, Atomic Energy Commission; FPC, Federal Power Commission; Ford zeg, Ford Foundation zero energy growth scenario; Ford tf, Ford Foundation technical fix scenario; Von Hippel, Frank Von Hippel and Robert Williams of the Princeton Center for Environmental Studies; ERDA, the Energy Research and Development Administration; EEI, Edison Electric Institute; Steinhart, 2050 forecast by John Steinhart of the University of Wisconsin; NAS 1, 11, 111, the spread of the National Academy of Sciences Committee on Nuclear and Alternative Energy Systems (CONAES); AW, Alvin Weinberg study done at the Institute for Energy Analysis, Oak Ridge; Lapp, energy consultant Ralph Lapp.

Amory Lovins put together this table showing the downward drift in forecasts. Figures represent total U.S. energy demand in year 2000 or 2010.

*Numbers are in "quads -- quadrillion BTU's." 1980 consumption was about 78 quads.

Source: Science 208 (20 June 1980): 1353.

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ridiculously low estimate of eight years earlier as their likely high growth future. The now conventional and conservative view -- reflecting several studies at the National Academy of Sciences -- sees between 67 and 100 quads for the turn of the millenium. The new madness -- the new hyper-radical view of the Steinharts -- sees a nation using only 33 quads per year, a sharp decline by the turn of the century from this year's consumption of about 80 quads.

Underlying these long-term demand shifts in energy forecasts are two factors. First, there are enormous opportunities for energy conservation. Second, the rates of consumption of energy intrinsic in the structure of the economy -- large public spaces, large private spaces, large automobiles, standard industrial processes, and so on -- are increasingly seen neither necessary nor desirable and hence will undergo severe technology change.

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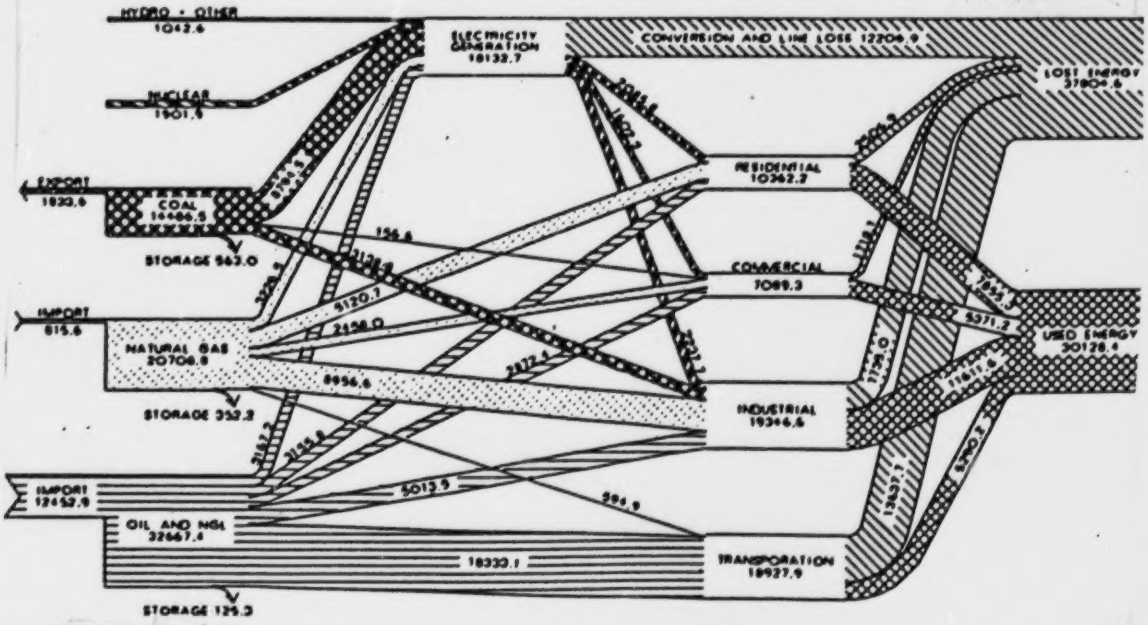
The wide variation in the values of credible forecast and the continuing downward trend in the forecast energy consumption for the year 2000 strongly urge that any attempt to anticipate the environmental effects of massive wood burning should not tie itself to any particular forecast of gross energy consumption. The drivers of more extensive use of biomass must find their rationale in factors other than aggregate demand. Focus should be on more robust or more powerful social economic forces. The next section discusses conservation as one of those forces.

HOW CONSERVATION RELATES TO BIOMASS

A sense of the scope that conservation offers for coming to grips with energy futures is shown in the 1975 flow pattern, Exhibit 4-4. The Los Alamos figures show the origins and the flow of energy in the United States economy. Well over half of the energy produced from all sources in the

EXHIBIT 4-4: ENERGY FLOW PATTERN, UNITED STATES 1975


HYDRO · OTHER 1042.6
NUCLEAR 1901.5
EXPORT 1830.6
COAL 14406.5
STORAGE 563.0
IMPORT 815.6
NATURAL GAS 20708.8
STORAGE 352.2
IMPORT 12452.9
OIL AND NGL 32667.4
STORAGE 125.3
ELECTRICITY GENERATION 18132.7
CONVERSION AND LINE LOSS 12206.9
RESIDENTIAL 10362.2
COMMERCIAL 7089.3
INDUSTRIAL 19346.6
TRANSPORATION 18927.9
LOST ENERGY 37804.6
USED ENERGY 30128.4
126.6
5120.7
2158.0
8956.6
2872.5
5013.9
594.9
18330.1
5371.2
7055.3
11611.6

Units	Trillions of BTU
Net Energy Imported	11434.9
Total Energy Produced	57538.6
Total Energy Consumed	67933.0
Population	213124000

*Source: R.P. Kidman et al, Energy Flow Patterns for 1975. Los Alamos Scientific Laboratory, June 1977: 72.

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United States in 1975 was lost either in conversion to electricity, in transmission of electricity, or in the simple inefficiencies associated with the processes for the use of energy in transportation, space heating, or industrial processes. Exhibit 4-4 also illustrates the minor role of biomass in the overall 1975 pattern. Biomass is subsumed with hydro and others, which represented 1.04 quads out of a total of 67.9 quads consumed; 57.5 quads were produced within the United States. Note also these numbers do not agree with Exhibits 3-2 and 3-3.

While the opportunities for managing energy costs on an individual and institutional basis are great and numerous, the stimulus for doing so is the increased and presumably increasing cost of conventional energy.

Exhibit 4-5, prepared by O'Neil of the Georgia Institute of Technology, shows the energy cost per million btu's of a variety of energy sources. The route to energy conservation through improved efficiency in processes

EXHIBIT 4-5: COSTS OF ENERGY*

Base: Atlanta, Georgia -- October 1979

Fuel/Feedstock	Energy Cost (per Million BTU's)
No. 2 Oil	$ 5.61
No. 6 Oil	$ 3.07
Coal	$ 1.82
Natural Gas -- Small User	$ 3.10
Natural Gas -- Large User	$ 2.40
Electricity -- Small User	$13.19
Electricity -- Large User	$ 7.32
Pulpwood	$ 1.70
Sawmill Residue	$ 0.51
Wood Pellets	$ 2.00
Wood Chips	$ 1.32

*Source: O'Neil, Daniel J., Wood Biomass for Energy, Georgia Institute of Technology, Atlanta, Georgia, 1980. Invited paper presented at the Southern Forest Range and Pasture Symposium, New Orleans, March 13-14, 1980.

and equipment is only one route. An alternative route is substitution of one fuel for another. It is clear from Exhibit 4-5 that all other factors being equal, the substitution of sawmill residues or pulpwood for either #2 or #6 oil would be attractive. Substitutions, however, are not limited to feedstock. They may also come at the technological level. For example, insofar as a small agricultural user is paying $3.10 per million btu's for natural gas he may find strong stimulus to use wood, wood chips, sawmill residues, or farm residues in a small farm gasifier to produce his own fuel equivalent of natural gas. Substitution may come in the form of local highly distributed technologies.

A third way in which conservation may interact with energy sources is suggested by Exhibit 4-6, which shows the distribution of energy on a percentage basis between residential, industrial, and transportation (38%, 36%, 26%) and as distributed by fuel source, electricity, gas, oil, and coal in each of those three categories. Insofar as residential and commercial use, whether electricity, gas, or oil is used for space heating, there are strong incentives to substitute stoves and fireplaces for domestic space heating or equivalent technologies for commercial space heating. As will be discussed in greater detail below, the substitution of wood for other fuels for domestic space heating has reached the point where such consumption is a substantial part of the overall energy consumption. Based on a recept Gallup poll of domestic fireplace and stove use, as much as 0.85 quads of wood are now consumed in that way (1). According to Paul Bente of the Bio-energy Council in his 1980 review of bioenergy in the United States, when firewood is effectively integrated into other estimates of bioenergy consumption including that of the wood products industry, wood now contributes about 3% to U.S. energy consumption (2).

PLAUSIBLE LIMITS ON BIOMASS ENERGY

The following are known sources of biomass energy:

A. Land Sources

1. Trees
2. Forest Residues
3. Forest Energy Plantations
4. Grasses
5. Cultivated Crops
6. Animal Manure and Sewage
7. Agricultural Residues
8. Food Processing Waste

B. Biomass in Short-Term Storage

*9. Paper and Municipal Solid Waste

C. Biomass in Intermediate Storage

*10. Dumps
11. Land to be Cleared

D. Water Sources

*12. Marine and Aquatic Plants

E. Other

*13. Plants Directly Producing Liquid Fuels

*As discussed in Section 3, Nos. 9, 10, 12, and 13 are outside the scope of present study.

EXHIBIT 4-6: 1978 U.S. ENERGY USE PATTERNS*

TOTAL PRIMARY ENERGY:	78 QUADS
Residential and Commercial Use	38%
Industrial Use	36%
Transportation Use	26%
RESIDENTIAL AND COMMERCIAL:	29.3 QUADS
Electricity	49%
Gas	26%
Oil	24%
INDUSTRY:	28.1 QUADS
Electricity	34%
Gas	29%
Oil	24%
Coal	13%
TRANSPORTATION:	20.5 QUADS
Oil	97%
Gas	3%

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*O'Neil, Daniel J., Wood Biomass for Energy, Georgia Institute of Technology, Atlanta, Georgia, 1980. Invited paper presented at the Southern Forest Range and Pasture Symposium, New Orleans, March 13-14, 1980.

Based on two extensive and recent reviews of these sources, those of the Mitre Corporation and the OTA, and additional material as appropriate, this brief review of the scope of those resources draws conclusions as to the imminent and long-term practical potentials for biomass energy.

1. Trees

Most of the practical, readily exploitable biomass sources are now found on land. In the United States there are about 730 million acres of timber. The total energy value of that timber is, at most, about 300 quads. For the sake of comparison, the total natural gas reserves are about 290 quads, the total proven oil reserves are about 200 quads, and coal reserves are about 4,000 quads. If one were to wipe out the forest completely to supply the national energy demand, those 300 quads would last about four years. However, one would not want to wipe out the forests. The renewable concept implies that one could harvest and regrow on cycles of anywhere from 4 to 100 years. Present steady state availability is about 7.5 to 10 quads per year.

As a rule of thumb, it now takes about 50 million cords of wood, or the yield of 6.5 million acres, to supply one quad of usable energy per year. As discussed in more detail below, the potential yield could be much higher with more intensive cultivation and the introduction of different species or improved varieties. That does imply, however, an overall increase in energy input. According to L. D. Garrett of the Rocky Mountain Forest and Range Experiment Station, USDA, the overall energy balance strongly favors output over input. He estimates that under present management practices the total energy required for planting, fertilizing, thinning, and for fire and disease control and management is approximately 0.003 quads, for a potential output of 6.5 quads. It works out to be an energy efficiency ratio of about 2,000 to 1. He further estimates that it could go as high as 2,500 to 1, and as low as 10 to 1 in highly cultivated so-called energy plantations (3).

Carrying the energy balance concept forward, about 0.292 quads would be needed for harvesting and transporting 6.5 quads of wood. Put differently, approximately 0.046 quads of energy are required to cultivate, harvest, and transport one quad of wood.

The OTA report converges on a range of potential use in assuming that 40% of the growth potential of U.S. commercial forest land is eventually accessible. Some 450 to 900 million dry tons (7.3 to 14.6 quads per year) would be available for harvest (4).

The current pattern of harvest is illustrated in Exhibit 4-7. Of a total of 5.3 quads equivalence of felled timber, approximately 1.5 quads per year are used for energy purposes, the overwhelming amount of which, 1.2 quads per year, is used to satisfy some 45% of the forest products industries' direct energy needs. Put more pointedly, there is one paper company which uses enough wood energy directly that its individual corporate consumption of wood energy is equal to one day of the United States' total annual energy consumption (5).

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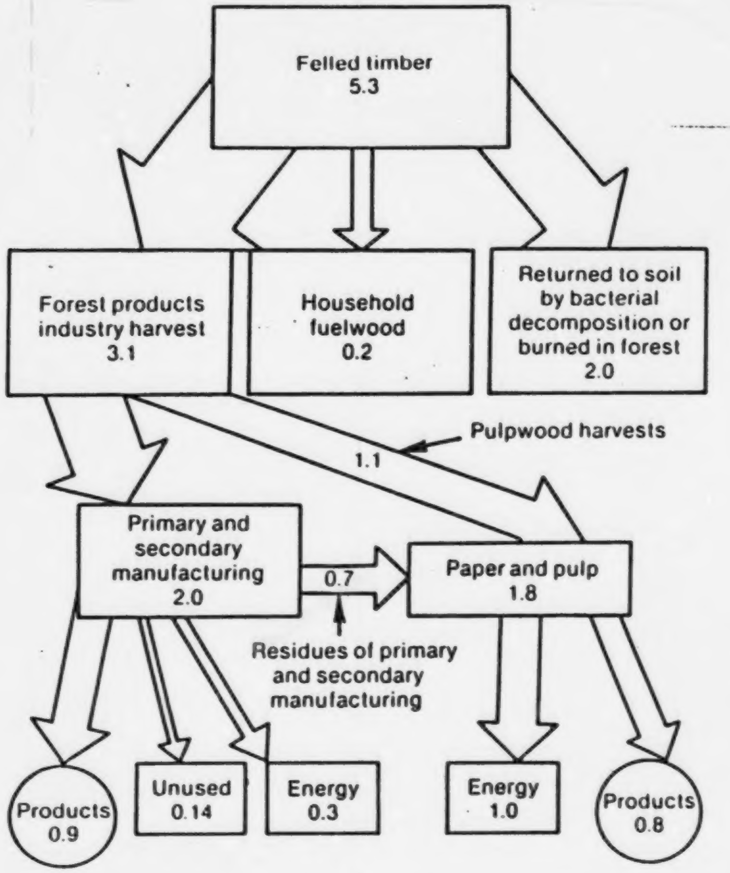
In addition to the portion of the 5.3 quads which end up consumed as energy, another 2.2 quads are cut but not used, and there is another 40 quads in total of unmerchantable timber left standing.

The OTA report carries its estimates forward to broadly estimate that 5 to 10 quads per year of energy potential will be realized from commercial forest lands by the year 2000. It takes into account increased demands for

EXHIBIT 4-7: MATERIALS FLOW DIAGRAM FOR FELLED TIMBER DURING LATE 1970's (Quads/yr.)


Felled timber
5.3
Forest products industry harvest
3.1
Household fuelwood
0.2
Returned to soil by bacterial decomposition or burned in forest
2.0
Pulpwood harvests
1.1
Primary and secondary manufacturing
2.0
0.7
Paper and pulp
1.8
Residues of primary and secondary manufacturing
Products
0.9
Unused
0.14
Energy
0.3
Energy
1.0
Products
0.8

Total left in forest	2.0 Quads/yr
Total used as energy	1.5 Quads/yr
Unused residues	0.14 Quads/yr
Total products	1.7 Quads/yr

Source: U.S. Congress, Office of Technology Assessment. Energy from Biological Sources: Volume II-Technical and Environmental Analyses, U.S. Government Printing Office, Washington, D.C., September 1980) p. 24.

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traditional forest products being balanced by increased forest production, improved management, and the likelihood of the forest products industry becoming totally energy self-sufficient (6). Exhibit 6-8 shows similar data and should be compared to highlight the uncertainity of good estimates.

2. Forest Residues

Forest residues are again a potential energy resource, significant in their own right. This will be discussed in greater detail in the section on wood. Of a total annual growth of approximately 8.2 quads, some 1.85 quads remain as forest residue, as dead, diseased, and deformed trees. As quite distinct from the net annual growth which is not harvested, the surplus growth added to forests each year amounts to about 2.6 quads.

3. The Energy Farm or the So-called Energy Plantation Concept

The energy farm proposal goes beyond the present concept of forest management for commercial purposes and would dedicate some forest areas totally or predominately to energy use. The kinds of trees, location, pattern, the radius served by the central power station, and other variables are discussed in greater detail in the next section on wood. For the moment, suffice it to say that there are two schools of thought on the energy farm. One school says that it is nothing more than an extrapolation of present trends and concepts toward managed growth. Others argue that the concept is more extreme and might require quite different forms of forest management, tree growth, species selection, etc.

4. Grasses

Grasses are another source of biomass. Approximately 1.1 - 2.2 quads are available from that source. Grass is not cheap to harvest and may not, therefore, represent a major practical source of biomass energy (7). Hay sells for $1.00 to $2.50 per fifty-pound bale. That is forty to ninety dollars a ton.

5. Cultivated Crops

From cultivated crops there is a potential of about 4 quads. Plants rich in starch and sugars, such as sweet potatoes, sweet sorghum, kudzu vines, and a number of others have their primary appeal as feedstock to ethanol production for use in gasohol which is outside the scope of the present study. The OTA report in its combined estimate of cultivated grass and other crops, notably corn, estimates that by the year 2000 anywhere from 0 to 65 million acres could be used for energy crops, and assuming grasses with a yield of six dried tons per acre, their energy potential is 0 to 5 quads per year (8).

6. Animal Manure

Manure is a potentially practical resource on the farm. Approximately half of all manures are deposited in the open range. The other half, principally from dairy cattle, cattle and feed swine, chickens and turkeys, is available for energy conversion. The technology is well known and widely used throughout the world for converting animal manures into so-called biogas. The net availability would be about .27 quads (9).

The use of human waste from sewage for biogas generation is technically quite practical. It is likely, however, that esthetic considerations and public health concerns will find other outlets for sewage.

The American Gas Association is quite optimistic about the use of cattle manure in biomass energy production through the production of anaerobic digestion systems which will lead to commercial quality gas. As current production according to their estimates is only 0.0006 quads, by the year 2000 they expect that to increase to 0.280 quads in their high estimate, a 400% increase over the present level of use (10).

7. Crop Wastes

Crop wastes are a biomass resource second only to wood in potential importance. The story is succinctly put by the OTA report:

> In summary, the total crop residue production in the United States is about 5 Quads/yr., of which about 3 Quads/yr. can be collected with current harvesting equipment. The quantity that can be collected while maintaining current soil erosion standards is about 1 Quad/yr. Considerations of a reliable supply, however, would reduce this to roughly 0.7 Quad/yr. of reliable feedstock, if soil erosion standards are strictly adhered to. By 2000, increases in crop production could raise this by 20 percent to 0.8 to 1.2 Quads/yr. (11).

8. Food Processing Wastes

Food processing wastes are an attractive biomass source since they bring together two attractive conditions for exploitation. They are a waste product which must be disposed of in order to avoid creating an environmental pollution, and also their very nature as food processing waste means that they have been collected at central places. The total amount of waste energy available from such waste is quite small compared to overall energy demand or even to biomass availability, running from .066 to 0.117 quads. The pattern as shown in Exhibit 4-8 is already being utilized to some extent. Cheese whey is being converted to ethanol, sugar cane bagasse is widely used as an energy source in Hawaii.

9. Land to be Cleared

If one moves to land clearing for any number of related purposes, the biomass to be harvested (one time only) would vary over an order of magnitude from perhaps 16 quads to 160 quads (12).

The large numbers are, of course, extremely misleading since the rate of land clearance is slow, and resources of that magnitude are not

EXHIBIT 4-8: THE TEN MAJOR AGRICULTURAL WASTES WITH POTENTIAL TO PRODUCE ENERGY

Wastes	Btu/yr × 10^{12}
Orchard prunings[a]	30-61
Cotton gin trash[a]	20-31
Sugarcane bagasse[a]	4-8
Cheese whey[b]	4-8[c]
Tobacco (burley)[a]	2.3
Rice hulls[a]	2.2
Tomato pumice[b]	1.3-1.8
Potato peel and pulp[b]	1.0-1.1
Walnut shell[a]	0.9
Citrus rag and peel[b]	0.3-1.0
Total	66-117

[a] Suitable for combustion or gasification.

[b] Suitable for anaerobic digestion or fermentation.

[c] Based on starch content of milk and the volume of cheese production from *Agricultural Statistics* (Washington, D.C.: U.S. Department of Agriculture, 1978).

Source: Office of Technology Assessment, Vol. II, p. 103, and R. Hodam, "Agricultural Wastes," Hodam Associates, contractor report to OTA, 1979.

practically available. The other side of the coin is that few would want to clear land at rates which would result in that amount of biomass production. A more useful number to consider in terms of land clearance is that one quad of energy requires about 50 million cords of wood or roughly 3.3 million acres of forest land. If one looks at the current rate of urban expansion, it amounts to about 825,000 acres per year. If all of that were forested, it would be equivalent to 0.25 quads per year (13).

SOME SUMMARY FORECASTS OF BIOMASS ENERGY FROM NOW TO THE YEAR 2000

Fortunately, several highly credible forecasts of biomass energy from now to the early part of the 21st century have been put forward, including that by the Congressional Office of Technology Assessment (14), the Mitre Corporation (15), and the Engineering Experiment Station of Georgia Tech (16), and Oak Ridge National Laboratory (17). As discussed earlier, 1980 biomass energy consumption is somewhere in the neighborhood of 2.4 quads.

OTA Estimates

Turning first to the OTA estimates, they offer a low and a high estimate for the year 2000 of 6 and 17 quads per year. (See Exhibit 4-9.) In their low estimate, 5 quads (83%) would come from forest wood. In their high estimate of 17 quads, 69% would come from wood, which would amount to a doubling of wood biomass energy (10.3 quads) with a substantial introduction of biomass grass from grass at 29% (5 quads).

The Mitre Estimates

The Mitre Corporation estimates, based on a synthesis of over a dozen

EXHIBIT 4-9: OTA YEAR 2000 HIGH/LOW ESTIMATES OF BIOMASS ENERGY

	Low Estimate 6 Quads/yr		High Estimate 17 Quads/yr	
	Quads	%	Quads	%
Forest Wood	5.0	83	10.3	59
Grass			4.9	29
Crop residue	.8	13	1.2	7
Manure	.1	2	.3	2
Agricultural processing waste	.2	2	.2	1
Ethanol from grain & sugar			.3	2

Calculated from U.S. Congress, Office of Technology Assessment. Energy from Biological Sources, Vol. 1, Figure 2, p. 5 (U.S. Government Printing Office, Washington, D.C., July 1980).

studies, see 9.2 to 14.9 quads as the potential biomass energy for the early 80's, a substantially higher estimate than OTA's for the year 2000. Again, forest lands comprise the dominant source in their estimates. Mitre's estimate for the early part of the next century sees a potential of 35 plus quads with the forest again dominating. Intensively managed forests would yield 17.9 quads, and another 5.2 quads would come from the conversion of some 54 million acres of grass and forest land into forest energy farms. (Exhibits 4-10, 4-11.)

Georgia Tech Estimate

Professor Daniel J. O'Neil of the Engineering Experiment Station at Georgia Tech, taking a quite independent cut at the problem, again estimates that forest materials will be the dominant factor in the future. Exhibit 4-12 shows both the total available and practical judgments about the capture potential. In addition to joining other analysts in seeing aquatic energy farms as an unknown, O'Neil categorized herbaceous farms as another unknown. As with others, he gives low credence to animal residues (0.1 quads) and crop residues (0.12 quads). Mitre sees crops as 1.6 quads in the 80's, growing one percent per year through the year 2000. The OTA report sees crop residues as 0.8 to 1.2 quads. O'Neil's assumptions are interesting and explicit. He excludes energy farms from one set of calculations. He based his calculations on U.S. Forest Service projections, excluding trees less than five inches in diameter DBH (diameter breast high). Nor did he include forests which are not now managed commercially. The DOE Report of 1978 from which O'Neil drew Exhibit 4-12 noted the following:

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TA,

EXHIBIT 4-10: MITRE ESTIMATES OF POTENTIAL BIOMASS FOR ENERGY IN THE EARLY 1980's* **

SOURCE	CROPS	HARVESTING RESIDUES	PROCESSING WASTES
Cropland	0.5	1.6	0.03 food processing 0.80 manures
Pasture and range	1.1 to 2.2	—	
Forestland	3.1 to 7.7	0.9	0.5 mill residues currently unused
Cities	—	—	0.7 municipal solid waste
TOTAL		9.2 to 14.9	

Note: Mitre derived these numbers from the following sources:

Davitian, H., 1979. "Crop Residues as a Fuel for Power Generation." Proceedings of the DOE Residue and Water Fuels Utilization Program Contractor Review Meeting. Department of Energy, Washington, DC.

Guymont, E.J. and J.E. Alpert, 1978. Availability of "Agricultural Processing Wastes" for Utilization as a Feedstock for the Production of Alcohol Fuels. Energy Resource Co., Cambridge, MA.

Jones, J.L. et al., 1978. Mission Analysis for the Federal Fuels from Biomass Program. SRI International, Menlo Park, CA.

Miller, K.A. and F.A. Schooley, 1978. Availability and Cost of Agricultural and Municipal Residue for Use as Alcohol Fuel Feedstocks. SRI International, Menlo Park, CA.

Office of Technology Assessment, 1980. Energy from Biological Processes, draft report, Washington, DC.

Society of American Foresters, 1979. Forest Biomass as an Energy Source. Study Report of a Task Force, Washington, DC.

U.S. Department of Energy, 1979. The Report of the Alcohol Fuels Policy Review, Washington, DC.

Van Dyne, D.L. and C.B. Gilbertson, 1978. Estimating U.S. Livestock and Poultry Manure and Nutrient Production. U.S. Department of Agriculture, Washington, DC.

Wahlgren, H.G. and T.H. Ellis, 1978. "Potential Resource Availability with Whole Tree Utilization." TAPPI, November 1978, vol. 61, No. 11.

* Johnson, R. Channing, et al, Energy from Biomass: A Technology Assessment of Terrestial Biomass Systems, Vol. 1 (Report MIR-80W259 for National Science Foundation: Mitre Corporation/Metrek Division, McLean, Va., December 1980), pp. 67-68.

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* Represents the energy value of the feedstock.

** Johnson, R. Channing, et al, Energy from Biomass: A Technology Assessment of Terrestial Biomass Systems, Vol. 1 (Report MIR-80W259 for National Science Foundation: Mitre Corporation/Metrek Division, McLean, Va., December 1980), pp. 67-68.

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EXHIBIT 4-11: MITRE ESTIMATES OF POTENTIAL BIOMASS FOR ENERGY IN THE NEXT CENTURY * **

SOURCE	POTENTIAL
Existing forests fully stocked, with intensive forest management	Feedstock - 17.9
Conversion of 54 million acres presently used as grassland or forestland into silvicultural biomass farms	Feedstock - 5.5
35 million additional acres of high-potential cropland	Alcohol fuel - 1.2, or biomass for burning or gasification - up to 6
Integration of energy production into the production of food, feed and fiber on existing cropland	Alcohol and methane - 2.5 or feedstock - 4.5 to 5.5
Intensive management of high quality eastern grassland	Feedstock - 2.5
Wastes at 1980 level plus 1 percent per year through 2000	Varied feedstocks - 2.7
Arid land species, wetland species	Untapped resource
Land protection and improvement projects that bring marginal land into the productive land base	Unidentified but substantial
TOTAL	35+

Note: Mitre derived these numbers from the following sources:

Carlson, R. et al., 1980. "The Technical Potential of Alcohol Fuels from Biomass," Subcommittee on Energy of the Joint Economic Committee of the Congress of the United States. U.S. Government Printing Office, Washington, DC. 65-944.

Fege, A.S., 1980. "Short-rotation Silviculture--What Yields Can We Expect?" Manuscript submitted to The Southern Journal of Applied Forestry.

The MITRE Corporation, 1977. Silvicultural Biomass Farms, vols. I-VI. MTR-7347. McLean, VA.

Society of American Foresters, 1979. Forest Biomass as an Energy Source. Study Report of a Task Force, Washington, DC.

U.S. Department of Agriculture, 1977. Potential Cropland Study. Statistical Bulletin 578. Washington, DC.

Zeimetz, K.A., 1978. Land Available for Biomass Production for Energy Generation. U.S. Department of Agriculture, Washington, DC.

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*Johnson, R. Channing, et al. Energy from Biomass: A Technology Assessment of Terrestial Biomass Systems, Vol. 1 (Report MTR-80W259 for National Science Foundation; Mitre Corporation/Metrek Division, McLean, Virginia., December 1980), pp. 76-77.

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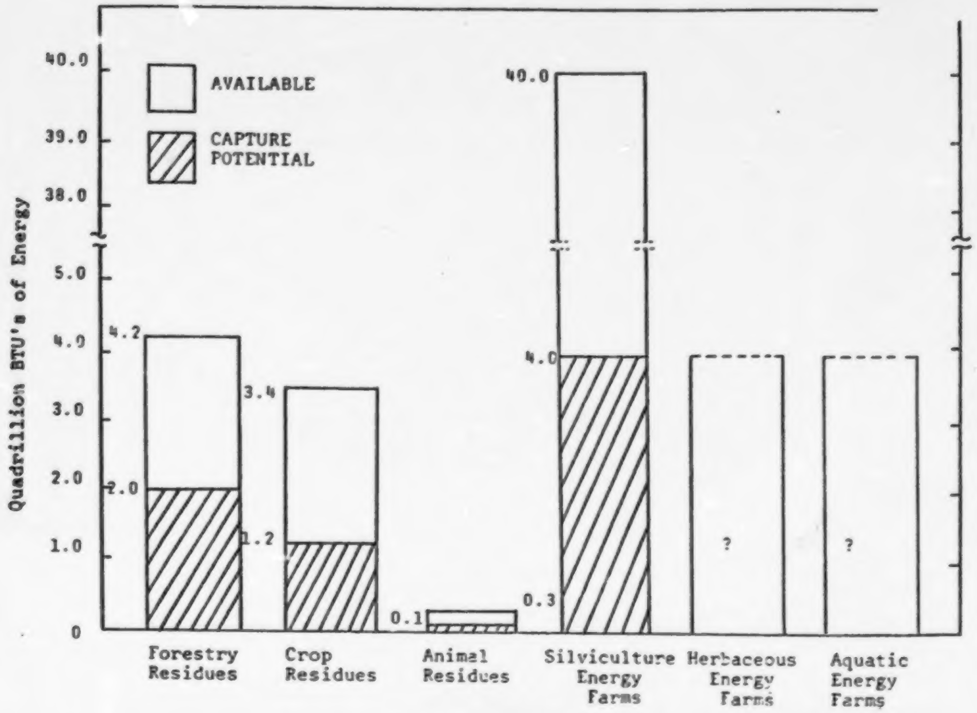
EXHIBIT 4-12: ESTIMATED POTENTIAL FOR SUPPLEMENTING U.S. ENERGY SUPPLY *



* Source: O'Neil, Daniel, Wood Biomass for Energy, Georgia Institute of Technology, Atlanta, Georgia, 1980.
Invited papers presented at the Southern Forest Range and Pasture Symposium, New Orleans, March 13-14, 1980.

"The principal markets for biomass are likely to be the supply of liquid and gaseous fuels and direct combustion. Direct combustion of biomass for heat, steam, and electricity is economic today, and contributes 1.3 quads annually, principally in the forest products industry. It appears practical to grow and harvest 4 to 5 quads of energy on silviculture energy farms. This concerted effort would require only 4 percent of the present U.S. forest acreage equivalent."(18).

Oak Ridge National Laboratory Estimate

In an independent analysis, C. C. Burwell of the Oak Ridge National Laboratory has estimated the potential collectible net yield from biomass operations under present management practices of 1974 (see Exhibit 4-13) (19) to represent a total collectible energy yield of 17.2 quads, 5.4 quads of which would be in residue values. This should be contrasted to a gross energy yield of 27.7 quads with a gross residue yield of 8.1 quads.

EXHIBIT 4-13: POTENTIALLY COLLECTIBLE NET YIELD FROM U.S. BIOMASS OPERATIONS UNDER PRESENT MANAGEMENT PRACTICES (1974) ●

Activity	Gross energy yield (Q)	Collectible net energy yield * (Q)
Agriculture		
Corn	3.9(1.9)**	3.0(1.8)
Grains	3.2(2.1)	2.9(2.0)
Green crops	2.2	2.1
Oil seeds	1.2(0.4)	1.1(0.4)
Fruit and vegetables	0.2	0.2
Other***	0.7	0.6
Silviculture	9.3(3.7)****	6.6(1.2)*****
Pasture and range	7.0	0.7
Total	27.7(8.1)	17.2(5.4)

*Energy inputs valued at 1.5 times the value of biomass energy. **Residue values given in parentheses. ***Taken as 10 percent of the total for all agriculture excluding corn in order to account for minor crop acreages not included in Table 1. ****All residues. *****Excludes tree leaves, small branches, and roots; includes stump, unmerchantable bole, and large branches.

● Burwell, C. C., "Solar Biomass Energy: An Overview of U.S. Potential," Science, vol. 199, March 1978, pp. 1043, 1045.

Exhibit 4-14 shows the major sources of potential usable biomass residue from Burwell's analysis in more detail.

He gives an interesting twist to the overall availability of biomass by showing both the energy and non-energy uses in Exhibit 4-15 for 1972 for both biomass and synthetic plastics, fibers and rubber. Burwell points out that all the annual production of biomass from fiber, wood and even food, equals a quarter of the nation's annual energy needs. Consequently, biomass can never be the dominant contributor but only a partial contributor to our energy supplies. He concluded the best present opportunities for exploitation are through programs to promote better forest management and incentives for installed small-scale equipment using wood fuels instead of oil and gas. He makes the interesting argument that marginal improvements in crops, such as corn for more intensive production, offer relatively small payoff compared to the margins of productive improvement available through more attentive cultivation of forests.

All the 20-year forecasts which attempt to give a balanced picture see wood as the dominant factor in biomass in the United States. Contrary to the current propaganda vogue, the forecasts put little stock in the economic viability of gasohol -- that is, alcohol derived from fermentation of crops.

EXHIBIT 4-14: MAJOR SOURCES OF POTENTIALLY USABLE BIOMASS RESIDUES •

Item	Weight (10^6 dry tons)	Energy* Total (Q)	Energy* Per acre (MBtu)
	Collected		
Urban and municipal solid wastes**	160	2.1	
Large poultry and hog operations and cattle feedlots***	26	0.3	
Large canneries, mills, slaughter houses, and dairies***	23	0.3	
Wood manufacturing****	15 to 27	0.4	
Total	-230	-3	
	Uncollected		
Cereal straw	161	2.1	22
Cornstalk	142	1.8	28
Logging residues****	50 to 75	1.1	130*****

*Residues evaluated at 13 MBtu per dry ton except for wood residues at 17 MBtu/dry ton. **E. L. Ellwood et al., The Potential of Lignocellulosic Materials for the Production of Chemicals, Fuels, and Energy (National Research Council, Washington, D.C. 1976), p. 6; available from the National Technical Information Service, Springfield, Va. ***National Research Council, Renewable Resources for Industrial Materials (National Academy of Sciences, Washington, D.C. 1976), p. 217. ****Ellwood et al., The Potential of Lignocellulosic Materials, p. 4; National Research Council, Renewable Resources for Industrial Materials, p. 217. ***** Estimated by the author assuming the large branches, stump, and unmerchantable bole are collected and that the total average aboveground residue is 9.1 dry ton/acre as given in K. Howlett and A. Gamache, Forest and Mill Residues as Potential Sources of Biomass (Report 7347, Mitre Corporation/Metrek Division, McLean, Va., May 1977), vol. 6, p. 75.

• Burwell, C. C., "Solar Biomass Energy: An Overview of U.S. Potential," Science, vol. 199, March 1978, pp. 1043, 1045.

As discussed earlier, ethanol, whether produced from cultivated crops or other sources, is outside the scope of this study and is the subject of a parallel study sponsored by EPA. With regard to grasses, they are not likely to be on anybody's high priority list for initial exploitation as a biomass energy source. Consequently, the economic barriers to cheap collection would have to be coped with technologically or overcome by the shifting price structures of other energy raw material. In either case, we see that there is ample time to study the implications of exploitation of grasses, should that approach become important.

EXHIBIT 4-15: DEMANDS FOR INDUSTRIAL BIOMASS MATERIALS AND FOR SYNTHETIC PLASTIC, RUBBER, AND FIBER IN 1972 •

Commodity	Tonnage (10^6)	Energy (Q)
Round wood requirement		
Structural materials	123	2.1
Pulp, paper, fiber	102*	1.7
Cotton and wool fiber**	3	0.2***
Biomass extractives		
Turpentine, rosin, tall oil****	1	
Vegetable oils*****	1	
Animal fat*****	1	
Animal hides	2	
Synthetics		0.6******
Plastics	12.5	
Fibers	3.1	
Rubber	2.8	

*Cellulose fibers account for less than 1 million tons. **Includes exports. ***Total for cotton and wool fiber, biomass extractives, and animal hides. ****Major uses include pine oils, rubber additives, paper size, adhesives, insecticides. *****Major uses include fatty acids, soap, and drying oils. ******Total for all synthetics.

• Burwell, C. C., "Solar Biomass Energy: An Overview of U.S. Potential," Science, vol. 199, March 1978, pp. 1043, 1045.

CONCLUSION

Interpreting these anticipatory studies, we conclude that the remainder of our attention should predominantly be given to wood, with lesser attention to crop residues, and with some attention to manure and agricultural processing waste simply because, while small contributors to the overall energy balance, they are to some extent preaggregated, and often there are economic or regulatory incentives for disposing of them.

As working numbers, current biomass is about 2.4 quads. For the year 2000 plus from 6 to 15 quads would be attainable, as reasonable, practical possibilities, and would be large enough to have effects on the environment meriting governmental attention. Should biomass assume these new levels of use, wood will be the dominant feedstock.

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SECTION 5

HOW TO GET USEFUL ENERGY OUT OF BIOMASS

PREVIEW

This section briefly outlines the means by which biomass is, or may be, converted to useful energy. It orients the reader and does some sorting to highlight those processes more likely, and those less likely, to be of practical significance. The various chemical and physical processes of conversion to useful fuel are discussed in fuller detail in later chapters.

HOW TO GET USEFUL ENERGY OUT OF BIOMASS

The situation is so complex and the processes are so numerous that first we have to develop a little vocabulary. The organic material which is the source of the energy -- that is biomass material (whether vegetable or animal) -- is called *feedstock*. There are a variety of processes by which feedstock is converted into usable energy. The most obvious *conversion* is to burn it, i.e., direct combustion. But for many other purposes, an intermediate stage is desirable in which the feedstock is converted into a higher priced, more conveniently managed, marketed, and transported liquid, solid, or gas. That conversion process yields an intermediate *fuel*. This is the basic vocabulary.

- *Feedstock*. The crop plants, or animal waste, that will be cultivated or collected, and processed for conversion, e.g., wood, agricultural crops, manure, algae, plant products.
- *Conversion*. Processes applied, singly or in tandem, to a feedstock to convert it to a more usable fuel.
- *Fuel*. Almost any form of fuel or energy conversion can be produced from a feedstock, depending upon the particulars of the conversion process. They include steam for heat and power, chemical synthesis feedstocks, alcohols, hydrocarbon oils, methane, and low- and medium-btu gas.

Settling on a particular feedstock or type of fuel desired limits the choices at other steps of the energy system. Some conversion pathways may be suitable only for some feedstocks. With current technology and economics, some conversions may be energy efficient for some feedstocks but not for others.

Exhibit 5-1 lists most of the convenient and conventional feedstock conversion processes and outcome fuels. To a large extent this report is concerned with embellishing on and clarifying those connections. (1)

EXHIBIT 5-1: FEEDSTOCKS TO FUELS: ELEMENTS OF THE CONVERSION PATHWAYS

FEEDSTOCK CHOICES

- Trees and Residues
- Crop Residues
  - -- corn stover, cobs
  - -- bagasse
  - -- rice straw
- Herbaceous Plants
  - -- grasses
  - -- cattails, reeds
- Marine Plants
  - -- kelp
- Aquatic Plants
  - -- water hyacinth
  - -- algae
- Food & Fibre Processing Wastes
  - -- peanut shells
  - -- cheese whey
- H_2 Producing Plants
- Animal Waste
- Fuel Producing Plants

CONVERSION CHOICES

- Direct Combustion
- Other Thermochemical Processes
  - -- pyrolysis
  - -- hydrogenation
  - -- gasification
  - -- air/oxygen gasification
- Biochemical Processes
  - -- anaerobic digestion
  - -- fermentation

FUELS OUTPUTS AND PRODUCTS

- Electricity
- Heat
  - -- industrial process steam
  - -- residential space heat
- Liquid Fuels
  - -- ethanol
  - -- methanol
  - -- fuel oils, char products
  - -- distillate
- Chemical feedstocks
  - -- ammonia, butanol
- Gaseous Fuels
  - -- methane
  - -- SNG
  - -- med-, low-BTU gas
  - -- product gases
  - -- hydrogen
- Solids

The processes by which one obtains energy from feedstocks are all chemical or biochemical. It is convenient and practical to divide them into three groups:

- o Direct combustion, that is, the direct burning of biomass, may be in a fireplace, a stove and industrial boiler or a central power station.
- o Thermochemical processes require heat to do something to the feedstock to convert it into a new fuel. Common thermochemical processes are pyrolysis, hydrogenation, hydrogasification, thermochecmical fermentation, air gasification.

- Biochemical processes include composting, anaerobic digestion and fermentation.

A brief note on each of these processes may help.

Direct Burning

This is probably the most straightforward and cheapest way to recover energy from biomass. Efficiency, in terms of heat recovery can be as high as 80%, but can be so low as to use more heat than it produces. A net heat loss can occur in the use of undamped fireplace chimneys in a well heated house. Direct burning is used to supplement or replace fossil fuel use in the home, a commercial building, an industrial facility, or at the power station.

Pyrolysis

This is a process in which biomass is heated to high temperatures (400 - 900°C) in the near absence of air to cause a decomposition into several combustible products -- char, oil, and gas. Some studies have shown a net loss of energy in the process -- more energy is expended than can be obtained from the products. Destructive distillation is pyrolysis applied to wood or wood refuse.

Hydrogenation

In this process hydrogen is added to carbon molecules in the substance by heating in the presence of a catalyst. Often the process uses carbon monoxide and steam at very high pressure (2,000 - 6,000 psi). Low sulfur oil can be obtained in this way.

Gasification

The gasification process is chemically very complex involving multi-stages but all within a single simple reactor.

Gasification technology is one of the cleanest conversion operations for coal and coke as well as biomass. Hydrogen sulfide can easily be removed from a gaseous stream by absorption techniques that have been used by the refining industry for decades. From an environmental point of view it is very attractive.

Hydrogasification

Organic wastes, such a manure, can be reacted directly with hydrogen gas at high temperature (500-600°C) and pressure (1,000 psi) to produce ethane and methane gas.

Acid Hydrolysis

Wood wastes can be treated with heat and acid to convert them into

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sugar. The sugar is then fermented and distilled to produce ethyl alcohol (grain alcohol).

Fermentation

Organic matter is decomposed by the action of yeast; ethyl alcohol is produced. This is the same process from which we get beer and wine.

Anaerobic Digestion

Anaerobic means "without air." The biological process by which plant or animal material is consumed and transformed in an air free container or environment is called anaerobic digestion. The bacteria in the anaerobic digester produce methane and carbon dioxide. That so-called biogas product can be used directly as a fuel or upgraded to a higher quality fuel. By-products of anaerobic digestion, the solid waste sludge, can be recycled to farmland as fertilizer or used as animal feed.

The process will start spontaneously with animal manures as feedstock. With other organic materials a starter is usually used.

CONCLUSION

Direct burning of wood is perhaps the most energy efficient of the above conversion processes. For example, it produces roughly five times the energy produced by burning ethyl alcohol made from the same quantity of wood.

By no means is the overall thermodynamic efficiency of the conversion process the only factor driving the choice among energy conversion processes. The choices depend on the available raw materials, the use to which the product will be put, limitations or requirements for transportation of raw material or the product, the price and availability of competing fuel supplies, etc.

While it is true that direct combustion does yield substantially more energy for a given amount of biomass, the practicalities of the market, the availability of raw materials, and a number of other considerations make it appealing to convert the biomass into an intermediate gaseous or liquid fuel.

For example, the people in the natural gas pipeline business have a strong interest in digestion of aquatic and marine plants because they may be a long-term source of methane. Methane could keep their pipeline full and profitable. Similarly, on a small scale, a farmer might not find it convenient to stoke up a boiler, but having a biomass generator for converting plant waste and manure into methane might be a good way to generate a multipurpose fuel. Moreover, since our automobiles, trucks, and tractors operate on liquid fuels, there has been major interest in getting liquid fuels from biomass.

The richness of the fuel products coming from these biomass sources is quite large. They fall into three general categories:

- liquid fuels; these include ethanol, methanol, and oils;
- gaseous fuels; these include methanes, medium-btu gas, and hydrogen;
- heat and electricity.

In addition, the processing yields chemicals or usable non-fuel by-products:

- alternative petrochemical feedstocks; these include ketones and higher alcohols;
- organic solid waste for animal food or compost.

In summary, since the most likely biomass fuels for substantial exploitation in the next decade or two are wood and wood waste, and crop and agricultural waste, and since the most likely sites for use are central power stations industrial facilities and space heating (particularly in residences), and in the use of agricultural and farm waste on the farm, the technologies of highest interest for their impacts on the environment are:

- direct combustion;
- gasification;
- anaerobic digestion.

The technologies will be discussed in fuller detail in the appropriate sections which follow.

SECTION 6

WOOD: RESOURCES AND THEIR LOCATION

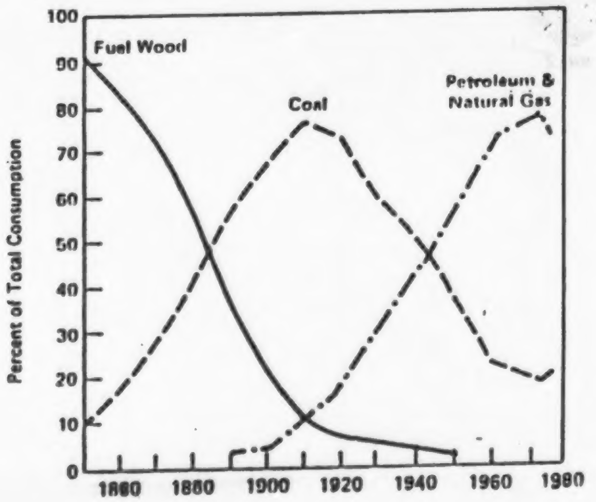
PREVIEW

This chapter reviews the historical and current patterns of use of wood as an energy source. It then outlines and briefly describes the location of principal forests and forest types and discusses potential and practical availability under current alternative forestry practices. While the current principal energy uses are within the forest products industry, there is a substantial and growing market for residential and commercial space heating and a trend toward wood in central power stations, outside the forest products industries.

HISTORICAL AND CURRENT USE OF WOOD ENERGY

In 1850 wood was the dominant fuel in the United States; 90% of energy came from wood. Coal's convenience, low cost, ready availability, and better industrial characteristics caused it to rise to ascendancy during the late 19th century, displacing wood. Coal, in turn, was largely displaced by petroleum and natural gas. See Exhibit 6-1.

EXHIBIT 6-1: UNITED STATES FUEL USE PATTERNS*



*Source: U.S. Department of Energy, Solar Energy: A Status Report, DOE ET-0062OUC-60, June 1978.

From its heyday, in the 1850's, the use of wood steadily declined. In 1940, 23% of homes were totally or partially heated by wood. The low point in home heating with wood was about 1970 when 1% of homes were so heated.

In New England in 1978, somewhere between 38% and 45% of owner-occupied homes used wood for space heating. That amounted to 1.5 million cords of wood, or the equivalent of 300 million gallons of heating oil. A cord of wood is a stack 4 feet by 4 feet by 8 feet, and is roughly equivalent to a solid block of 70 - 85 cubic feet of wood. In New England, wood is also being increasingly used in business and industrial processes. Some 150 New England companies use wood to generate steam and electricity. The wood used for that purpose is equivalent to about 2% of the region's annual oil demand.(1)

More recent reports find even greater residential use of wood. The Worldwatch Institute indicates that 7% of U.S. homes in 1981 are heated, at least in part, by wood stoves and furnaces. In New England it runs about 50%.(2)

A recent study by K. E. Kawadka of the Aerospace Corporation for the Department of Energy found:

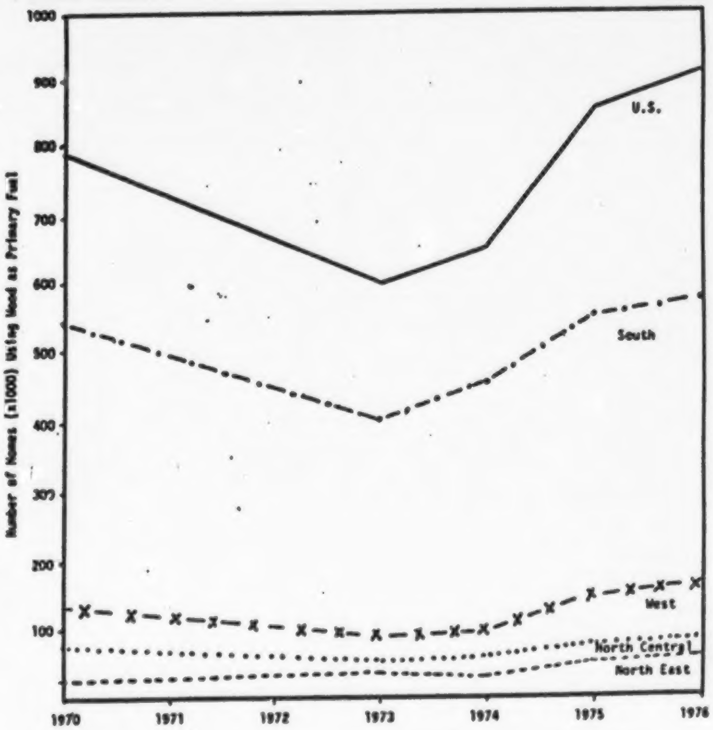
> "The popularity of home wood heating is increasing in several regions of the country. Exhibit 6-2 depicts the trend in recent years. In 1970, out of a total of 63 million occupied homes, 800,000 used wood as a primary fuel. During 1970 to 1973, the use of wood heating declined, but it increased approximately 50% from 1973 to 1976. This represents a net increase of 15% from 1970 to 1976. Over 900,000 homes were reported as using wood in 1976; over half of this use was in the South. Other regions have also experienced renewed interest. In the New England area, wood energy use has grown sixfold since 1970, and in Maine, Vermont, and New Hampshire, 18% of all households rely on wood fuel as their primary heating source. Some sources regard even this as a drastic underestimate of current wood use for space heating."(3)

Since the use of wood in the home is rapidly increasing it is no surprise that the numbers from the various studies are all not congruent. For present purposes it is sufficient to note that the use of wood in residential heating is on the rise.

Currently, the big user of wood, based on a percentage of the energy supplied, is the forest products industry. In 1980, 71.8% of energy in 16 reporting companies of the industry was derived from wood waste that could not be used in their wood products.(4)

With regard to the use of wood energy by the forest products industry, it is the case that now, and almost certainly for the short term, what amounts to waste in the forest and at the mill are the principal sources of new readily available energy. Aside from the rising cost of alternative

EXHIBIT 6-2: RESIDENTIAL USE OF WOOD AS A FUEL*



*Source: Annual Housing Survey, U.S. Department of Commerce as reported in K.E. Kawadka, "Health Effects of Residential Wood Combustion": Survey of Knowledge and Research, U.S. DOE: DOE/EV-011Y, Sept. 1980.

sources of energy, there are other incentives to the use of forest energy. The thinning of forests, the harvesting of the so-called unmerchantable woods, and other cultural work in the forest could improve the quality and growth rates and reduce fire hazards in some stands.

The Forest Service in its report on The Recommended Renewable Resources Program - 1980 Update (5) sees additional potential uses of large volumes of wood for energy, including the brick and cement industry, public and private institutions and municipal power generation plants.

There is growing use of wood energy in central power stations where in some cases facilities burning other fuels are being converted to wood. In other cases wood is used in conjunction with other fuels to make the system versatile and flexible in the face of an uncertain future for energy costs. For example, in Burlington, Vermont, a 9-megawatt converted coal boiler is used with a mixture of oil and wood to produce electricity for the city. It has been in successful operation since 1977. Burlington plans to build a 50-megawatt wood chip furnace that would consume 500,000 tons of wood chips a year, and provide electricity for 20,000 residents. According to the

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Worldwatch Institute the $76 million plant would cost 20% less to operate than a coal-fired plant(6).

SOME SUCCESS STORIES IN THE USE OF WOOD ENERGY

The Department of Energy has put together a useful collection of biomass success stories; Exhibit 6-3 lists 19 that are working and practical. They are practical from the rudimentary point of view -- they are economically a functioning part of the industrial operation. Public utilities, and wood products industries, which have ties to the raw material, are prominent. But there are other applications in manufacturing and in space heating.

Exhibits 6-4 and 6-5 describe the situation in which Canada's largest paper mill gets 52% of its total energy from its waste. It is interesting to note with regard to Exhibit 6-5, there are several energy sources -- wood residues and black liquor waste product of pulping are the dominant supply, but oil and electricity contribute. Exhibits 6-6 and 6-7 illustrate cogeneration, electric power, and heat on a university campus and show an operation that has been going for over 30 years. Particularly interesting is the energy distribution flow diagram. Exhibit 6-7 shows a relatively small amount of purchased electricity in relation to the overwhelming amount of wood residues used. The exhibit also illustrates the waste in combustion losses compared to the heat converted to steam. Cogeneration undoubtedly will play an increasing part in our diversifying energy mix. The energy which is used for electricity or for industrial processes generally results in a large amount of what is called waste heat. That waste heat can now be used for a number of other purposes, such as space heating.

Exhibits 6-3 to 6-7 show that wood is a commercial energy resource well past any state of mere pilot plant evaluation. While there are numerous technological developments which will improve the capabilities of wood as a resource for direct combustion, there is no question that even within the framework of the present technology there are major technological obstacles to its further expansion. The principal limitations on wide use are:

- Present and anticipated price structure of alternative fuels and the uncertainty of interfuel competition;
- Public policy strategies toward alternative fuels;
- The interaction between wood and transportation costs. Wood is in many physical characteristics like coal, but substantially more bulky for equivalent energy content. Consequently, the cost for transportation is relatively more than the cost for the transportation of coal.
- A dominant concern in the utilities industry and among industrial operators who generate their own energy is of assurance of fuel supply. Energy generation facilities are big capital investment, generally amortized over decades rather than years. Hence, assurance of fuel supply is critical to economically

EXHIBIT 6-3: SUCCESS STORIES IN THE USE OF BIOMASS*

Sugar Industry	No. 1	**Sugar Mill, Hawaii** — Power generated from sugarcane residue supplies 20 percent of electrical demand on the Island of Hawaii.
	No. 2	**Oahu Sugar Mill, Hawaii** — Energy recovered from sugarcane residue is used in cogeneration of electricity and low pressure steam for sugar mill operations.
Pulp and Paper Industry	No. 3	**Abitibi Paper Co., Pine Falls, Manitoba** — Energy recovery from wood residues supplies 10 percent of process steam at a sulphite pulp and paper mill.
	No. 4	**Abitibi Paper Co., Smooth Rock Falls, Ontario** — Kraft pulp mill supplies nearly all steam requirements from mill residues.
	No. 5	**Bowater Southern Paper Corporation, Calhoun, Tennessee** — Utilization of wood residues at the largest U.S. paper mill reduces oil consumption and alleviates local disposal problems.
	No. 6	**MacMillan Bloedel Ltd., Powell River, B.C.** — Wood residues provide 54 percent of total energy requirements at Canada's largest paper mill.
	No. 7	**Boise Cascade Paper Mill, Rumford, Maine** — Dry barking procedure at pulp mill simplifies residue handling and enhances energy recovery.
	No. 8	**Bowater Mersey Paper Co., Liverpool, Nova Scotia** — Improved energy recovery and capacity to utilize new wood species result from adoption of dry barking technique at pulp mill.
Manufacturing Industry	No. 9	**K. W. Muth Co., Sheboygan, Wisconsin** — On site burning of industrial residues provides energy to heat an entire manufacturing and warehousing facility.
	No. 10	**Van Isle Moulding and Millword Ltd., Langford, B.C.** — Resolution of a surplus material disposal problem in a millwork company produces unexpected energy benefits.
	No. 11	**Russel Corporation, Textile Mill, Alexander City, Alabama** — Textile mill derives steam for bleaching and dyeing operations from a wood fired boiler plant.
	No. 12	**Furniture Manufacturing Company, North Carolina** — Energy for air conditioning of furniture factory is obtained by burning dust recovered from the air itself.
Public Utilities	No. 13	**Eugene Water and Electric Board, Eugene Oregon** — Wood residues produce steam for central heating and electric power.
Wood Products Industry	No. 14	**Crown Zellerbach; Northwest Wood Products Division, Omak, Washington** — Plywood residues replace propane as a source of heat for veneer drying.
	No. 15	**Arcata Redwood Company, Brainard, California** — Wood residues provide energy for drying lumber.
	No. 16	**Fourply Inc., Grants Pass, Oregon** — Recycling of veneer dryer exhaust in conjunction with a wood fired heating system reduces emissions from plywood factory.
	No. 17	**Olson-Lawyer Lumber Inc., Medford, Oregon** — Process gas from charcoal production supplies 80 percent of energy for process steam at a lumber mill.
	No. 18	**Woodex Inc., Brownsville, Oregon** — Pelletized industrial fuel made from biomass residues competes with coal.
Space Heating	No. 19	**Home of C. J. Grant, Hibbing, Minnesota** — Efficient home space heating combines simple wood stove with natural convection.
	No. 20	**Agricultural Engineering Building University of Maine, Orono, Maine** — Small institutional heating plant utilizes chipped forest residues.
	No. 21	**University of Oregon, Eugene, Oregon** — Cogeneration of electric power and heat for a university campus.

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* Source: Biomass Energy Institute Inc., Biomass Energy Success Stories: a Portfolio Illustrating Current Economic Uses of Renewable Biomass Energy (Report HCP-T0285-01 UC-61: U.S. Department of Energy, March 1978).pp. i and ii.

EXHIBIT 6-4: PULP AND PAPER INDUSTRY, SUCCESS STORY NO. 6

WOOD RESIDUES PROVIDE 52 PERCENT OF TOTAL ENERGY REQUIREMENTS AT CANADA'S LARGEST PAPER MILL*

Location

MacMillan Bloedel Ltd.
Powell River, British Columbia

Background

The Powell River Division of MacMillan Bloedel operates the largest newsprint mill in Canada, with a capacity of 1860 tons per day, and annual production of about 600,000 tons. The energy required to operate this mill amounts to the equivalent of 13.5 million kWh per day, an amount comparable to the electrical energy consumption of a community of 700,000. Over 52% of this energy is supplied from renewable biomass derivatives.

Energy Production

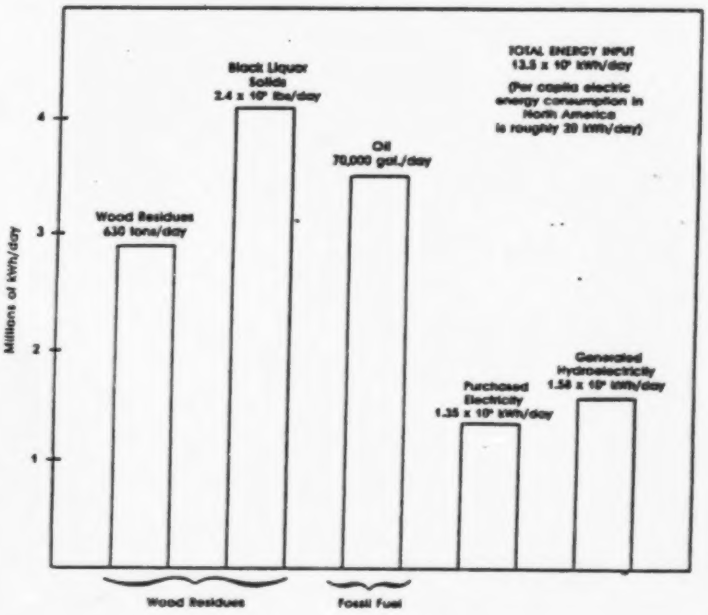
Figure 6a shows an energy input profile for the mill (in electrical equivalents) in which the basic energy sources are wood residues, black liquor, fuel oil, on-site hydroelectricity, and purchased electricity. Of these, wood residues and black liquor constitute renewable biomass energy sources. (Wood residues result from debarking operations while the biomass content of black liquor is made up of wood materials which are chemically dissolved during pulping operations as described in Success Story No. 4.)

All of the energy in wood residues, black liquor, and fuel oil is converted to steam with an efficiency of about 50%. A portion of the steam is employed to generate electricity while the remainder is used throughout the mill as process steam.

Evaluation

Although there is nothing unique about the recovery of energy from biomass in pulp and paper mills, this particular situation serves to demonstrate the scale on which it is possible to gather and utilize such energy.

EXHIBIT 6-5: PROFILE OF ENERGY INPUTS AT POWELL RIVER PAPER MILL**



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*Source: Biomass Energy Institute Inc., Biomass Energy Success Stories: a Portfolio Illustrating Current Economic Uses of Renewable Biomass Energy (Report HCP-T0285-01 UC-61: U.S. Dept. of Energy, March 1978). p. 41.

**Ibid, p. 12.

EXHIBIT 6-6: SPACE HEATING SUCCESS STORY NO. 21

COGENERATION OF ELECTRIC POWER AND HEAT FOR A UNIVERSITY CAMPUS*

Location

University of Oregon
Eugene, Oregon

Background

Since 1951 the University of Oregon at Eugene has been burning surplus wood residues from nearby mills to meet most of its energy requirements. In an excellent example of cogeneration, facilities have been established to generate 60% of electrical power from steam driven turbines, while exhaust steam supplies energy for all heating and cooling requirements on a campus of 17,000.

Energy Recovery

Surplus wood residues in hogged (shredded) form are delivered to the university power plant by truck from surrounding mills, with annual volumes amounting to roughly 70,000 units (1 unit - 200 cubic feet). Upon receipt, the wood residues are screened and large pieces are shredded in a small hog. Hogged chips are burned in 3 Combustion Engineering dutch ovens capable of producing 35,000 lbs. of steam per hour, plus a suspension fired Erie City boiler producing 110,000 lbs. of steam per hour.

Over 1 billion pounds of steam are generated annually to operate 2 condensing steam turbines plus a back pressure turbine. These turn generators which produce 20 to 30million kWh of electrical power annually, enough to supply 60% of total electric power demand. Exhauststeam from the back pressure turbine is employed to provide heat for campus buildings in the winter, or to operate absorption chillers in summer, the latter being used to chill water for air conditioners.

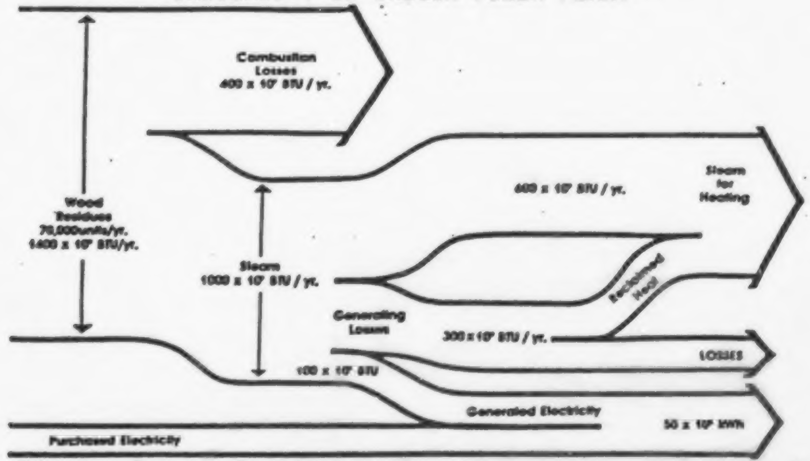
Economics

Because of the low cost of hogged wood residues in the area, the final cost of steam is about 30¢ per 1000 lbs., which compares to $2.40 per 1000 lbs. using oil at $12.00 per barrel. Considering that annual steam production is 1 billion pounds, the savings over oil amount to more than $2 million. By contrast, the 1976 bill for Bunker C oil used for standby purposes amounted to less than $4000.

Performance Evaluation

Performance over the years has been very satisfactory with additions being made as heating and electrical loads increased. During this time, scrubbing units have been added to meet pollution standards by removing particulates from the flue gases. Further efforts at the moment are directed toward the use of refuse derived fuel from Lane County. This fuel would be burned in conjunction with hog fuel in the suspension fired boiler.

EXHIBIT 6-7: DISTRIBUTION OF ENERGY INPUT AND OUTPUT AT THE UNIVERSITY OF OREGON POWER PLANT**



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*Source: Biomass Energy Institute, Inc. Biomass Energy Success Stories: a Portfolio Illustrating Current Economic Uses of Renewable Biomass Energy, (Report HCP-T0285-01 UC-61: U.S. Dept. of Energy, March, 1978)., p. 42.

**Ibid.

sound planning. The price of low-quality chips in Vermont in 1978 to 1979 varied from over $12 per green ton to a high of $26, returning to $16. Such price variations make it very difficult for potential industrial users to get a firm estimate of their future energy costs (7).

The Mitre study cites several additional factors which may limit wood's use for energy:

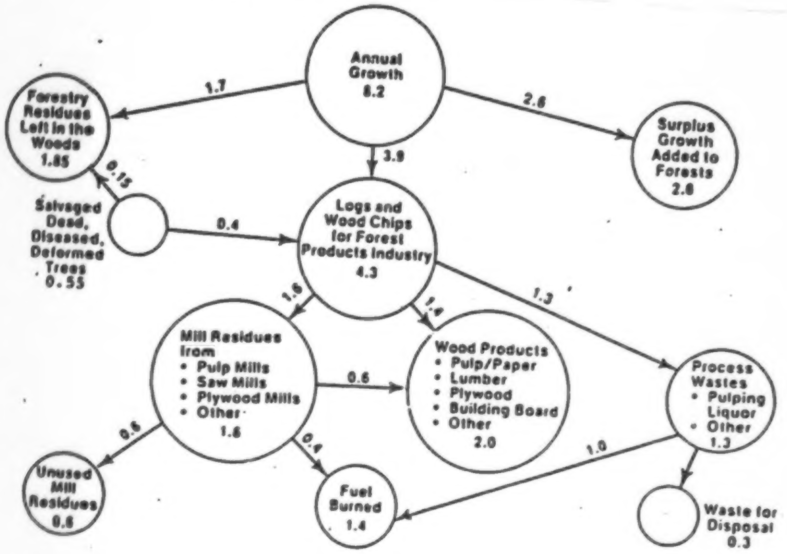
- The much higher capital cost of required wood combustion equipment compared against coal-fired systems because of federal oil and gas use restrictions -- 60 to 70% higher than comparable costs for a low-sulfur coal facility. A 700 MMBtu/hr low-sulfur, coal-fired facility has a capital cost of $24 million, whereas a similar wood-fired facility would cost $40 million.
- Suppliers of wood chips face similar problems -- without an assured market for their products financing is difficult.
- Bankers rate wood systems unfavorably in comparison with oil-fired systems. Doubts persist about the future supply of wood, and bankers generally do not understand wood-fired systems, especially when used outside the forest products industries.
- There is some evidence that industries which use substantial quantities of process heat and steam, such as the chemical, textile, food processing, and ceramics industries, do not view wood combustion as "sufficiently reliable."
- Unprocessed wood usually contains 50% water. That raises transportation cost and reduces the thermal efficiency of the boiler.
- Wood as a fuel involves handling difficulties. Contrasted to this, wood is bulky, requires care in storage to keep it dry, and has ash removal problems (in contrast to oil and gas)(8).

This brings us, therefore, to the next set of considerations -- resource availability.

FORESTS: THEIR SIZE AND ENERGY CONTENT

Earlier it was pointed out that there is about 300 quads of energy stored in the forests of the United States. That is roughly equivalent to four times the total annual energy consumption of the nation. The key factor is the annual growth rate, i.e. the amount that could be skimmed off for energy consumption because it would be replaced by new growth. The annual growth is about 8.2 quads. One overview of the disposition of that 8.2 quads is found in Exhibit 6-8. Roughly 2.6 quads of unused growth is left in the forest as additional annual growth; 1.8 quads is left as residue. After

EXHIBIT 6-8: DISPOSITION OF FOREST BIOMASS (1976 Data-Quads/Year)*


Annual Growth 8.2
1.7
2.6
3.9
Forestry Residues Left in the Woods 1.85
Surplus Growth Added to Forests 2.6
0.15
Salvaged Dead, Diseased, Deformed Trees 0.55
0.4
Logs and Wood Chips for Forest Products Industry 4.3
1.6
1.4
1.3
Mill Residues from
• Pulp Mills
• Saw Mills
• Plywood Mills
• Other
1.6
0.6
Wood Products
• Pulp/Paper
• Lumber
• Plywood
• Building Board
• Other
2.0
Process Wastes
• Pulping Liquor
• Other
1.3
0.6
0.4
1.0
Unused Mill Residues 0.6
Fuel Burned 1.4
Waste for Disposal 0.3

*Source: Mittelhauser Corporation, Wood Combustion Systems: Status of Environmental Concerns, Report DOE/EV-0064 UC-61 for U.S. Dept. of Energy (National Technical Information Service, U.S. Dept. of Commerce, Springfield, Va., January 1980).

From "Near Term Wood Combustion Workshop," at Mitre Corp., McLean, Va., (January 11, 1979).

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going to market for milling wood products or pulping, 0.6 quads are unused as mill residues, and about 0.3 quads are left over in the form of pulping liquor and other wastes. That adds up, therefore, to about 4.45 quads left in the forest each year and another 0.9 quads available at the mills as wood waste. Comparison of Exhibit 6-8 with Exhibit 4-7 may be useful in highlighting the uncertainty of good estimates.

In addition to the commercial wood in commercial forests, there is about 20 - 40 quads of non-commercial wood standing on commercial forest lands -- about a fifth is salvageable dead trees. Almost all of this dead wood is in the western United States. The removal of these dead trees would definitely enhance the quality of those forests. But all estimates of the total available forest energy and the annual growth rates are open to revision, generally upward. The Forest Service, which is the primary source of data in this regard, has based its estimates on commercially significant supplies. So, for example, Forest Service estimates generally do not report bark residues, stock on logged over areas, trees less than five inches in diameter at breast height, trees that are classified as rough or rotten, trees from non-commercial species, tops and branches, and stumps. The Forester's Wood Energy Handbook highlights the importance of these neglected factors(9). In a Southern Pine some 18% of the wood energy is in the roots, 67% in the stem, and 15% in tops and branches. The OTA estimates that in addition to the 22.1 billion dry tons of biomass standing timber on U.S. commercial forest land, when one adds non-commercial land (defined below), that gives 27 billion dry tons (430 quads). Their estimate excludes stumps, foliage and roots and the biomass in parks and wilderness areas or other areas being considered for such use(10).

While the accuracy of these estimates within broad ranges are not important to the present study whose concern is in environmental effects of much more extensive use of biomass, these estimates are of some importance when it comes to projecting potential forest biomass availability. Also questionable according to OTA's analysis are the annual growth rates based on the standard mechanism for estimating forest growth by the so-called normal yield tables of the Forest Service.

The OTA reports that in both field experiments and in the questioning of industry representatives about comingled Forest Service and industrial forests plans, the yield tables are often off by two to four times. On that basis OTA estimates that the annual growth is between 570 and 1140 million dry tons (9 to 18 quads per year). According to Forest Service estimates, some 20 million acres of commercial forest land are understocked, even more land is stocked with less than optimal species. If fully stocked with highly productive species, the Forest Service estimates would find yields rising from a present value of 38 cubic feet per acre a year to 74 cubic feet per acre per year. With OTA's correction factor of two to four times the normal yield tables, that would give 1.1 to 2.3 billion dry tons per year (18 to 36 quads per year) with full stocking of productive tree species on commercial forest lands. This would correspond to two to four tons per acre per year on the average.

As the report points out, OTA is assuming unfertilized growth. In studies in the Southeast, they report that fertilizers and genetic hybrids could increase the biomass growth by 30% (11).

THE ENERGY EQUIVALENCY OF WOOD AND TREES

Not all wood is equivalent in energy, whether green, that is, newly harvested or seasoned.

The difference between green and seasoned wood can be important from an energy efficiency point of view. Since any moisture residual in the wood must be driven off by heat produced by that wood any technique for pre-drying or reducing the moisture content gives greater efficiency. Many kinds of wood contain 30% to 50% moisture on harvesting and with one year would drop to 30% and give perhaps 10% more heat, and in a residential use, more even burning(12).

Resin content can also strongly influence the heating quality of wood. A typical hardwood would have an average heating value of 8,500 btu's per pound and soft woods having more resins would have an average heating value of 8,900 btu's per pound.

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Even more important than the variations in energy content of individual wood are the gross characteristics of trees since that determines to a great extent the overall productivity of the forest. As O'Neil and many others point out, rapidly growing trees for silviculture energy plantation might be designed around short rotation times of six to ten years(13). For an energy plantation that is a highly intensely cultivated forest for energy exploitation,yields might rise to 12 to 13 dry tons per acre compared to current yields of 4 to 8 dry tons per acre for hardwood. O'Neil's regional analysis of the potential for southern wood energy finds that in 30 million acres or 10% of the southern states in Soil Conservation Service capability classes I-IV now used as forest, pasture, and range of the total land at a yield of 8 dry tons per acre would result in 4.5 quads of energy feedstock per year.

Specific experimental examples of short rotation hardwoods are shown in Exhibit 6-9.

EXHIBIT 6-9: EXPERIMENTAL SHORT-ROTATION HARDWOODS*

Species	Location	Rotation (Yrs.)	Yield**
Sycamore	Mississippi	2-3	5-7
Red Adler	Washington	4	8.5
Black Cottonwood	Washington	4	6
Hybrid Poplar	Wisconsin	4	8
Eucalyptus	Florida	5-6	3.5

*Source: O'Neil, Dr. Daniel J., Wood Biomass for Energy, Georgia Institute of Technology, Atlanta, Georgia, 1980).

Invited paper presented at the Southern Forest Range and Pasture Symposium, New Orleans, La., March 13-14, 1980.

**Oven-dry tons/acre.

WHERE THE FORESTS ARE

The location of the forests is shown in Exhibit 6-10. The bulk of the wood is in the Northwest (Washington and Oregon) and in the Southeast and South Central states. Roughly 80 quads are in the Pacific Coast states, and another 80 in the South and South Central states.

Exhibit 6-11 shows the distribution of forest lands as a percentage of the total land area of each of the states. This sharply highlights the regional aspects of wood resources.

Forests cover about one-third of the United States, or 740 million acres. Of those 740 million acres, about one-third are reserved as parks and wilderness areas. Consequently about 488 million are commercial forests. The definition of commercial forests as officially used by the Forest Service is generous. The requirement is the production of only 20 cubic feet/acre of wood annually and that the land not be set aside as woodland or parkland.

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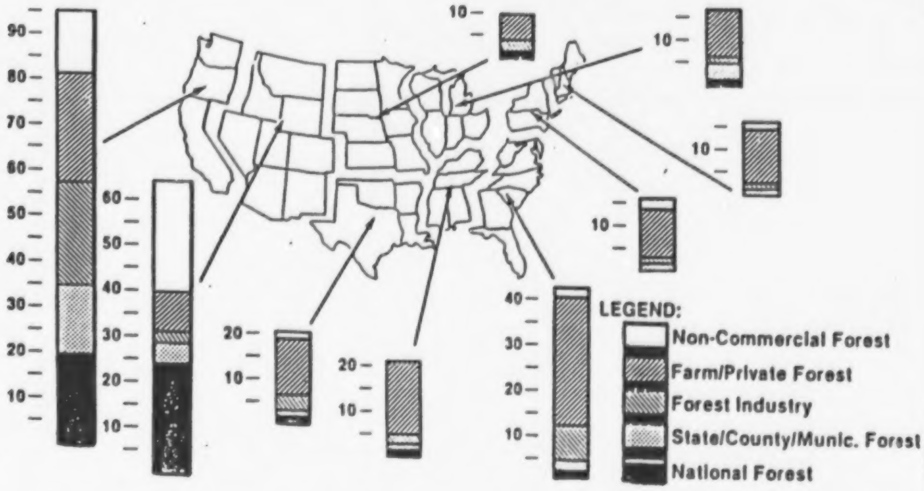
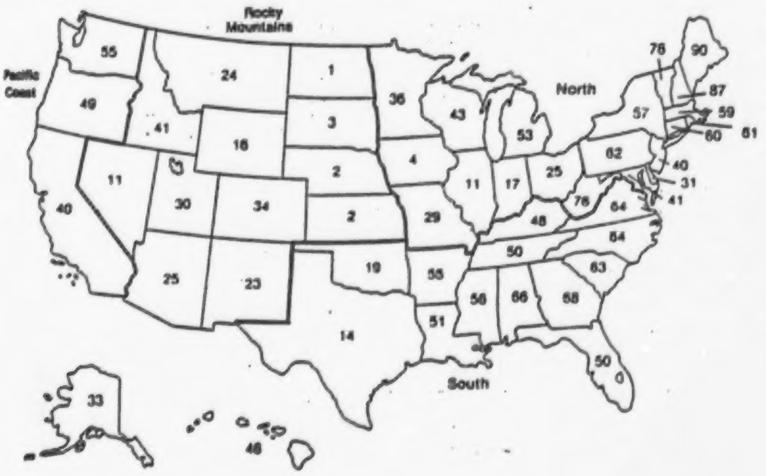
EXHIBIT 6-10: DISTRIBUTION OF THE STANDING FOREST RESOURCE QUADS BY REGION*



Calculated from "Outlook for Timber in the United States," USDA/USFA, 1974. Total Energy Equivalent = 300 Quads.

*Source: D.Salo, et al, Near-Term Potential of Wood as a Fuel, (Report HCP/T4101-02 UC-61 for U.S. Dept. of Labor; Mitre Corp./Metrek Division, McLean, Va., August 1978).

EXHIBIT 6-11: FORESTLAND AS A PERCENTAGE OF TOTAL LAND AREA*


Rocky Mountains
Pacific Coast
North
South
55
49
40
41
11
24
18
30
34
25
23
1
3
2
2
19
14
36
4
29
55
51
43
11
53
17
25
48
76
64
64
50
56
66
68
63
50
62
57
78
90
87
59
60
61
40
31
41
33
46

*Source: U.S. Congress, Office of Technology Assessment, Energy From Biological Sources, Vol. 1 (U.S. Government Printing Office, Washington, D.C. July 1980), p. 60, from Forest Service, U.S. Dept. of Agriculture.

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What that amounts to is that commericial forests are 22% of the area of the United States and 66% of total forest land.

There are important differences among the major forests of the United States. The Pacific Northwest first growth is still predominant; in the Northeast, there are 100-year forests reflecting replenishment of the countryside, begun after a period of excessive use and restoration. In the Southeast, where short rotation pine plantations are common, the forests are all secondary or tertiary growth and the use and rapid turnover is a standard part of the regional economy.

The Northwest, the Southeast, and the South Central states have the greater amount of available resources. But economics may make it more attractive to promote development in the North Central (Minnesota, Wisconsin, and Michigan) and the New England states. In those areas the wood is currently of lower value and, hence, perhaps more exploitable. On the other hand, social attitudes in the South, and the already well-established wood harvesting industry may make that a more attractive area for early development.

WHY OWNERSHIP CAN HAVE ENVIRONMENTAL IMPACTS

Of the commercial forests in the United States 58% is held by non-industrial private landowners. These people -- farmers, physicians, laborers, and others -- hold forests for a variety of purposes. Hunting, solitude, and natural beauty are cases for owning forests(14).

Of privately owned forest land plots in Tennessee 87% are under 50 acres (15). They are the prime target for forest management information and education. Industrial forest managers, in so far as it has been in their own interest, generally maintain a healthy standing crop of trees under sustainable yield. Small private owners do not have the long-term economic incentives that forest industries do. Even if they have the knowledge and ability, as few of them do, to manage plots productively, many may be tempted to sell if the price of wood goes up, to reap short-term profit.

Some non-industrial private owners manage their lands for timber products and do an exemplary job, but most are either not interested in cutting the wood or are unaware of opportunities for scientific forest management. It is owners in the latter category who are of primary concern. As the price of timber goes up and the demand for firewood increases, the likelihood of significant numbers of owners allowing their lands to be stripped increases. In most states there is little control over the exploitation of privately held forest lands. The risk is that hundreds of thousands of acres of timberland may be exploited as landowners seek to make a quick profit. It creates a potential need to monitor and regulate forest management practices at the state level to avoid large-scale exploitation of privately-held forest resources.

TVA has developed the Woodland Resource Analysis Program to assist the private landowner in managing his land both for his needs and for the health of the forest. This innovation merits close watching as a possible model for other areas.

The significance of ownership is reinforced by Burwell's analysis, already mentioned, which makes the point that the principal practical short-term payoff in production of forest energy is in applying technologies and techniques for cultivation which we already have, in other words, to manage relatively under- or unmanaged current commercial forest which does not require any technological breakthrough but only using the knowledge we now have (16).

SECTION 7

SILVICULTURE AND CONVERSION PROCESSES

PREVIEW

In order to understand the possible beneficial, uncertain and adverse environmental impacts, it is necessary to review the alternative for forest management, the technological cycle from planting and harvesting to ultimate use, and the processes by which the trees are converted into usable fuel. The next section will cover impacts.

SILVICULTURE

The art of growing trees is called silviculture. Silviculture is the analogue of agriculture or animal husbandry. The cycle of cultivation consists of planting, steady state maintenance, and, in some cases, a long-term rotation with non-energy crops.

In understanding impacts, it is convenient to look at the sequence from cultivation to consumption as consisting of the following phases:

- o cultivation
- o harvesting
- o transportation
- o processing
- o conversion -- that is, the processes of making wood into lumber, furniture, veneer, paper, or for use as an energy source.

Cultivation. The elements of cultivation are shown in Exhibit 7-1. Some marginal, uncommon, or experimental elements are included for completeness.

Harvesting. There are different styles of harvesting. The most drastic and the easiest to understand is the process called clear-cutting, in which all the trees in an area are cut down. These areas may run from several acres in small patches, to hundreds of acres in large patches. All of the harvestable wood is removed, usually leaving behind unmerchantable and low quality trees and residues -- tops, branches, leaves.

The alternative major practice is selective cutting, in which individual cuttings are based upon size, density, particular species, and so on.

EXHIBIT 7-1

ELEMENTS OF CULTIVATION

SITE SELECTION

LAND PREPARATION

- Clearing
- Tillage/Plowing
- Laying of irrigation pipe
- Sowing: seeds, seedlings, cuttings, clonal propagation
- Compost fertilization

STEADY STATE

- Fertilization
  - nitrogen fixing plan
    - legumes, co-cultivated
    - N-fixing bacteria
    - non-legumes
    - rotation of crops
    - co-culture of crops with complementary nutrient requirements, e.g., alders, mesquite, something that fixes its own nitrogen
  - chemical
    - application of by aerial spray
  - municipal sludge
- Soil warming with waste heat or buried pipelines (not yet commercial)
- Irrigation
  - municipal sludge
  - enhanced rainfall (hypothetical)
  - methods: drip, sprinkler, furrow, flood
- Weeding
- Pesticides
  - rodenticides
  - herbicides
  - chemical insecticides
- Genetic techniques
  - for protection from insects
  - for enhancing resistance of trees
- Fire protection
  - physical: roads, residue clearing
  - preventive chemicals
  - fire extinguishing techniques: water, foam, chemicals
- Hormone treatment (not yet commercial)
- Genetic manipulation for increase in fiber, cellulose growth or resistance (now at research stage)

Selective cutting is strikingly different from clear-cutting and may have to do with improvement of the quality of the forest. Clear-cutting also has to do with the quality of the forest. Some species and some sites respond most productively to clear-cutting, some to selection, some to other methods.

Logging to pick up residuals in the forests would be particularly appropriate for energy purposes. YUM Systems (yarding of unmerchantable materials) pick up the toppings and de-limbed limbs and often serve in traditional forestry the purpose of removing residual combustibles.

Harvesting equipment is listed in Exhibit 7-2 and illustrated in Exhibit 7-3.

Some new equipment requires comment -- notably the densifiers and the chipper. The chipper is a large piece of equipment which takes a whole tree or any portion of a tree and converts it into small-size chips, usually running several inches in dimension. The chipped wood is then loaded into trucks or vans and moved. Harvesters and chippers are often combined.

Densifying equipment consists of a large press which squeezes the wood into a higher density state. It thereby converts it into a more convenient and portable size and shape. Densifying yields pellets or extruded shapes. There are three basic types of densified wood -- fuel logs, stoker fuel, and pellets.

Other processes linked to harvesting include drying -- either heating in the sun, heating with stack waste gas, or allowing natural air drying. There is also technology for separation, storage, and transportation.

Several machines are likely to have significant effects on the forest by changing management and harvesting:

- the whole tree chip harvester -- this is a large device which can take a whole tree in the forest and reduce it to wood chips. The principal environmental consequences one may anticipate from this process is that the nutrients, especially those concentrated in the branches of the tree, will be removed from the forest;

- swath cutting -- this technology, involving large mobile clippers, may strongly promote clear-cutting. Clear-cutting could affect the texture of the terrain and run-off of nutrients, etc. The swath cutter and whole tree chip harvester can be used together and with the same results;

- sludge injection -- this is an application technology which is already beginning to be used in forests. It is a move to a more agronomic model rather than a forest preservation model of management. The effect of the sludge may be to create the excessive run-off of nutrients from the sludge into streams. A second effect may be the accumulation of trace metal materials in the

EXHIBIT 7-2

ELEMENTS OF HARVESTING

SYSTEM FOR ACCESS TO HARVEST SITE

- Permanent Base -- launching periodic harvests, storage
- Temporary Base for Harvest Site
    - roads, bridges
    - rail system
    - flight path clearance
    - canals or waterways

HARVESTING EQUIPMENT

- Chainsaws
- Axes
- Cable Harvesting System
- Swathcutters
- Mechanized Tree Feller
- Helicopters
- Blimps
- Dirigibles
- Aerial Cable
- Wheeled and Track Skidders
- Residue Collectors (alone or with other equipment)
- New Technologies ? ? ?

HARVESTING SUPPORT EQUIPMENT

- Trucks
- Railroads
- Boats
- Garages
- Fuel Suppliers for Harvesting Equipment
- Living Quarters and Sanitation Facilities
- Processors: chippers, densifying equipment

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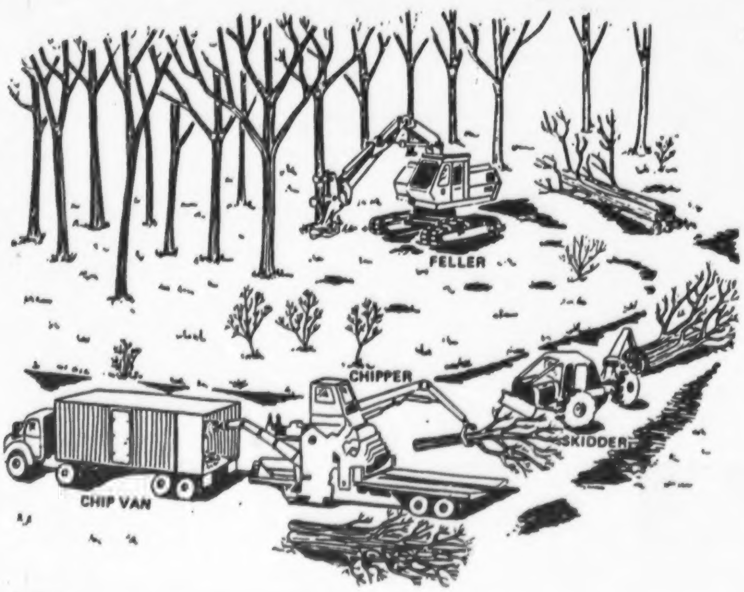
EXHIBIT 7-3: TYPICAL EQUIPMENT FOR HARVESTING FOREST RESIDUES ON GENTLE TERRAIN (Fig. provided by the Forest Service)*



*Source: GAO EMD 81-6 - March 3, 1981, The Nation's Unused Wood Offers Vast Potential Energy and Product Benefits.

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animal populations of the forests. The trace metals could accumulate in deer which are eaten by people. The problem is not likely to be major, but it is, nevertheless, real. There may be beneficial side effects -- the sludge from urban areas will be usefully disposed of;

- dirigibles and helicopters -- both are already in use, but there seems to be little evidence that their use will expand. Nevertheless, some monitoring should be done of their use in removal of wood from less accessible areas. Particular consideration should be given to their usefulness in avoiding road and skid construction and other environmentally stressful alternatives;

- on-site densification -- the ability to convert forest material into more easily managed higher density material may be a major technological development. It may lead to more widely marketable wood products for residential markets. The present so-called "Presto Logs" are one example of this densification technology. When done on a larger scale and marketed differently, the wood products may open up a major market in residential heating. It should also be noted in this connection that densification may open up foreign markets to wood. Domestically, densification and pelletization should expand the market for wood among both commercial and residential users by reducing transportation costs and making handling easier.

Depending upon the kind and intensity of technology brought to bear on forest management, one can see five distinct stages, each of which has different environment implications. They are on a continuum of increasing intensivity of treatment:

STAGE 1
MODEST DISTURBANCE of the forest,
limited to removing dead materials

STAGE 2
TIMBERSTAND IMPROVEMENT - removal of material to
relieve crowding, remove undesirable species, and
thereby promote production.

STAGE 3
HARVESTING all available material for fuel

STAGE 4
CLEAR CUTTING and replacement of
existing species

STAGE 5
SITE CONVERSION for
short rotation intensive culture (SRIC)

These five stages are, in fact, continuous but conceptually representative of significant break-points in the extent to which people intrude upon the forest ecosystem. One goes from the mere clearing out and selective removal, at Stages One and Two, to the total management and perhaps to what one might characterize as a forest energy factory at Stage Five. A fuller note on the forest energy factory may be useful.

The term "energy plantation" was coined and trademarked by George Szego of Intertechnology Incorporated in 1972 to describe a concept which goes well beyond the central power station. The notion of an energy plantation is to explicitly grow, manage, and harvest over a long period of time the forests necessary to sustain a pre-established major central power station. It is a full systems concept for wood and forest exploitation, but goes further in planning and managing forests to meet the requirements of the central power station than current practice.

Szego, his associates at Intertechnology, and William J. Oswald of the University of California at Berkeley, have gone a step further and proposed a photosynthesis energy factory which would tie the energy plantation (which is dependent on woody plant matter which is chipped and used as a solid fuel) to an algae production system (using the nutrients in the waste water and

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the carbon dioxide in the power plant exhaust gas to produce algae). (1) The algae would be harvested and digested anaerobically to produce methane; the digester sludge would be disposed of in a beneficial way by being put back onto the energy plantation.

The concepts which Szego sees the demonstration of an energy plantation would achieve are:

- use of "marginal" land;
- use of land on a large scale;
- yields and plantation design;
- advantages of deciduous species, effects on yields and economics
    - fast juvenile growth
    - multiple harvests through coppicing
    - reproduction with clones
- mechanization of plantation generations;
- sustained yields over a period of time;
- maintenance of productivity of land;
- water requirements;
- materials handling operations.

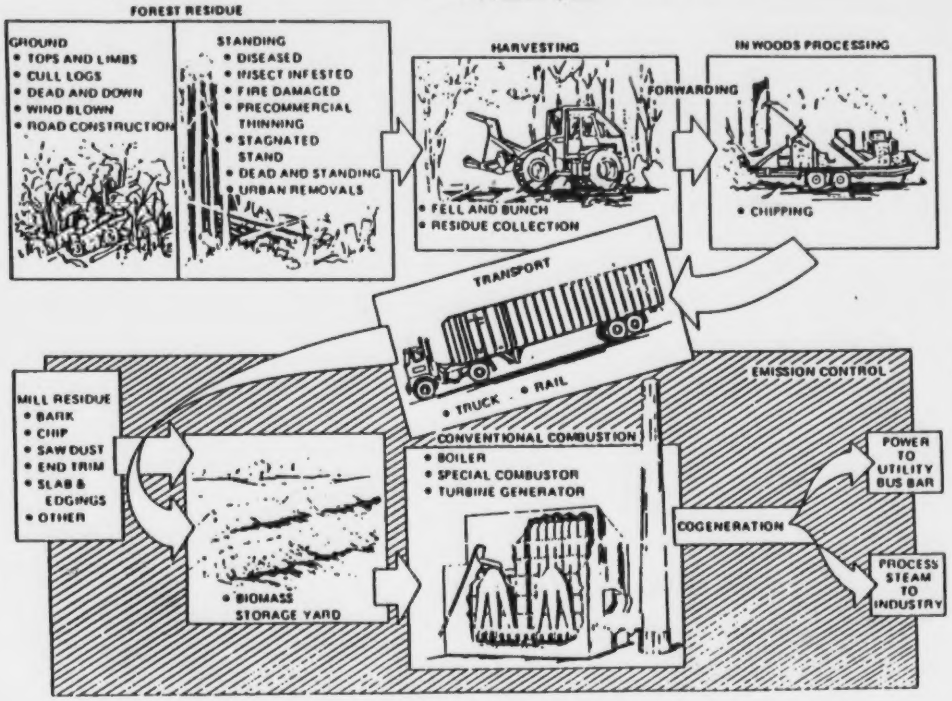
MOVING AND USING WOOD

Exhibit 7-4, prepared by the Resource Policy Center of Dartmouth, illustrates the biomass energy flow from the forest to the central power station. Examination of that diagram would show that some subsidiary technological steps might be intruded -- densifier, pelletizer, etc. There might be a variety of storage alternatives for the wood, and the wood itself might be shipped in different forms depending upon the purpose for which it was being shipped: (2)

- direct burning in fireplaces, stoves, or furnaces in residences or small commercial establishments;
- direct burning in boilers at homes for space heating or hot water;
- in industries for power generation in the form of electricity or process steam;
- gasified to use in a boiler or to upgrade to synthetic natural gas;

- pyrolyzed to produce methanol, pyrolysis oil or synthesis gas.

EXHIBIT 7-4: BIOMASS ENERGY FLOW CONCEPTS*


FOREST RESIDUE
GROUND
• TOPS AND LIMBS
• CULL LOGS
• DEAD AND DOWN
• WIND BLOWN
• ROAD CONSTRUCTION
STANDING
• DISEASED
• INSECT INFESTED
• FIRE DAMAGED
• PRECOMMERCIAL THINNING
• STAGNATED STAND
• DEAD AND STANDING
• URBAN REMOVALS
HARVESTING
• FELL AND BUNCH
• RESIDUE COLLECTION
FORWARDING
IN WOODS PROCESSING
• CHIPPING
TRANSPORT
• TRUCK
• RAIL
EMISSION CONTROL
MILL RESIDUE
• BARK
• CHIP
• SAW DUST
• END TRIM
• SLAB & EDGINGS
• OTHER
• BIOMASS STORAGE YARD
CONVENTIONAL COMBUSTION
• BOILER
• SPECIAL COMBUSTOR
• TURBINE GENERATOR
COGENERATION
POWER TO UTILITY BUS BAR
PROCESS STEAM TO INDUSTRY

*Source: Resource Policy Center, Dartmouth College, Environmental Report: Advanced Systems Demonstration for Utilization of Biomass as an Energy Source, September 1980: pp. 1-5.

A BIG WOOD BURNING CENTRAL POWER STATION

Fortunately, the Resource Policy Center at the Thayer School of Engineering at Dartmouth has just issued an environmental report on the first phase of an "Advanced Systems Demonstration for the Utilization of Biomass as an Energy Source." (3) The specific objectives of the program were to:

- establish that sufficient fuel wood can be collected at a reasonable cost to support and sustain such a plant;
- evaluate the energy system's reliability and thermal efficiency;
- demonstrate that the energy produced from such a system with wood fuel would be available at a competitive cost;

- evaluate the environmental and socioeconomic impacts of harvesting, collecting, and transporting fuel wood and operating the power plant;

The first phase task accomplished the:

- location of a reliable long-term source of fuel capable of providing 1,000 tons per day of fuel (oven-dry basis);
- selection of an existing harvest and collection system to provide the plant's daily fuel supply;
- preparation of detailed cost estimates for those steps;
- determination of the price of wood fuel for the plant;
- selection of a suitable location for the plant;
- preparation of an engineering design for the plant;
- projection of capital and operating costs;
- preparation of an environmental report.

One of the more interesting findings of the study is that to achieve this level of energy generation, it would be necessary to cover a 50-mile radius around the power station to assure 1,000 tons per day of wood fuel.

Exhibit 7-5 is an extensive extract from the Dartmouth study which should illustrate the numerous complex considerations entering into the wood burning central power station.

Big is, of course, a relative term when speaking of central power stations. Compared to a coal-fired or nuclear power station which might be in 800 megawatts (MWe) a big wood burning facility might be 5% of that, 40 megawatts or so. As already indicated, the economics of hauling biomass as well as factors of assurance of supply could be major determinants setting upper limits on their size. By no means, however, are central electric generation stations the only significant use for wood. Wood fired plants could have broad application on a localized basis for small and medium size industrial facilities to produce process heat and steam. The emphasis and description in this section is on the upper end of size, simply because that is the range most likely to stress the environment, whether or not properly and effectively managed.

The environmental effect of these and other technologies will be discussed in the next chapter.

Diagram of a typical boiler from the Foresters Wood Energy Handbook is shown in Exhibit 7-6. A total bark burning boiler system used in East Millinocket is shown in Exhibit 7-7. According to estimates from Professor

EXHIBIT 7-5

THE WESTBROOK MAINE POWER STATION *

The S. D. Warren Company mill in Westbrook, Maine, was chosen for the final, in-depth investigation. The use of a single site for analysis provides a focus for detailed investigations; however, the findings developed have generic application to the industrial use of wood for energy throughout the country.

The concept of the operation is shown in Exhibit 7-6 for a wood-fired power plant. Forest residues will be harvested, chipped in the woods, and transported to the proposed plant site in large chip vans. Mill residues will be purchased from companies currently disposing of wood waste and shipped to the proposed plant by rail car or chip van. Approximately 15% of the fuelwood will arrive by rail: the remainder will be transported by chip van.

The facility is designed for continuous operation, twenty-four hours a day, seven days a week, for 340 days a year. The plant will shut down for scheduled maintenance and repair to assure continuous operation for the remaining 340 days.

The plant will require a fixed fuel supply rate of 1,000 oven-dry tons per day of wood fuel stock which will be converted to heat to produce steam. The steam, in turn, will pass through a turbine-generator to generate electricity. Steam leaving the turbine will still have a substantial amount of heat energy that can be sold for process and heating purposes to the steam user. The proposed power plant will deliver electrical energy to the utility company to be sold in the same way as utility-generated power. Co-generation of steam and electricity allows more efficient use of the wood fuel.

The plant will be controlled to balance the production of electrical energy such that the steam user will receive his needs first, and the remainder of the energy will be converted to electricity for the utility company. Under normal (i.e., average) design conditions, the facility will sell approximately 26 megawatts of energy to the steam user in the form of steam and approximately 18 megawatts of energy to the utility company as electricity. Approximately 6 megawatts of energy will be consumed by the internal operation of the generating plant.

Process Description

The plant's design and operating features will be integrated into the existing system.

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* C. E. Hewett, Colin High et al, Resource Policy Center, Environmental Report: Advanced System Demonstration for Utilization of Biomass as an Energy Source, Report #292, Dartmouth College, New Hampshire, Sept., 1981

The woodyard will provide approximately 1,000 oven-dry tons of wood per day to the boiler. Since the wood actually received will be green and contain about 50% moisture, the fuel-handling and boiler system must be designed to handle two thousand tons of green fuel wood daily. Two thousand gallons of number 6 fuel oil will be fired daily to maintain a standby energy source in case of emergency. This will allow the boiler to remain on line without interruption of steam production. No more than 2.5 million gallons of number 6 fuel oil will be fired annually in the standby and emergency modes combined. The boiler will also be designed so that it can be readily retrofitted to burn coal.

The wood furnace will heat the boiler to produce 510,000 pounds per hour of steam for delivery to the turbine-generator. The turbine-generator will produce approximately 25 megawatts of electric energy and provide about 480,000 pounds per hour of steam at 560 and 50 pounds per square inch gauge (psig).

An air pollution system will be installed to cleanse the flue gases to a level that meets the applicable U. S. Environmental Protection Agency and Maine Department of Environmental Protection standards. Integrated with the stack emission system will be a series of flue gas bark dryers that will predry the fuelwood as it is fed from the wood pile to the boiler. An ash pond will contain the ash sluiced from the boiler and the air pollution control equipment prior to the ash's ultimate disposal in a landfill. The water used to sluice the ash will be recycled to sluice additional ash.

Biomass Fuel Supply

Forest fuel for the plant will be procured from private logging contractors who in turn will purchase the timber cutting rights from landowners. Millwood residues will be purchased from wood products firms in the region. Because wood will be obtained from a wide variety of private sources, it is impossible to specify precisely the fuelwood procurement region.

The annual production of tops and limbs within a 50-mile radius of Westbrook in Maine only could supply 1.9 times the plant's annual tonnage (see Table 1.2.3-B).

Within a 75-mile radius of Westbrook would be approximately 6 times the wood required to fuel the facility.

In a 75-mile radius, the tops and limbs currently being wasted could supply 1.8 times the annual fuel needs of the wood-fired facility. The excess growth in this area appears to be approximately ten million tons per year.

The Wood Energy Institute prepared estimates of the rough and rotten standing timber within a 50-mile radius of Westbrook; this material totals 70 times the wood-fired plant's annual requirements for fuel. About two-thirds of this material is in Maine.

Mill residues could provide a second principal fuel source. Sawdust, bark, shavings, and slabs from sawmills and other forest products plants are materials that are of low commercial value and may be going to waste or creating a disposal problem.

The positive responses indicated that a total of 405,000 green tons of mill residues could be obtained annually for an average cost of $5.63 per ton.

Biomass Fuel Handling

The system designed primarily for waste materials will have one tilt-up truck dumper and a clamshell bucket for railcar unloading. The materials received by this system will go to a primary screen that will separate the oversize materials from the acceptable materials. Oversize materials will be reduced in size by an operation called hogging and then blended with the materials passing the screen. The waste from the screen and hog will normally go to the storage pile, but can be routed through an alternate path that by-passes the storage pile and goes directly to the boiler.

The storage pile will hold about thirty days' supply of fuel and will have a "live" storage area with two reclaiming screw conveyors, each capable of providing 7,360 tons of fuel without any re-supply of the live storage area. The screw conveyors will take wood from the bottom of the pile. This procedure will make use of the heat from the biodegradation activity within the pile and avoid any snow or ice that may have accumulated on top of the pile. The screws will travel under the center of the pile for a total distance of some 960 feet or 96% of the pile length. An overhead conveyor belt with small bulldozer will also be employed to spread the fuel and fill empty spaces.

Emergency Fuel Supply

Number 6 fuel oil will be fired continuously with the fuelwood at a rate of two thousand gallons per day (1.5% of the total btu input) to ensure a readily available standby fuel system.

O'Neil of Georgia Tech, there are approximately 2,500 wood burning boilers in use in the United States today. (4) Not all boilers are custom built or erected in the field -- only the very large units. Smaller units are available as package boilers -- some companies offer commercial turnkey systems.

McGowan, in his comparison of wood, coal, gas, and oil, points out that the capital costs of wood and coal systems are higher than those for gas and oil, the higher cost resulting from the cost of the boiler, process equipment, and fuel handling equipment. (5) On the other hand, the fuel cost for coal, wood chips, and wood waste are less than those of gas and oil. Technological developments in both the heating system and the wood pelletization may eventually affect the future price structure. According to McGowan, wood fuel can be the lowest overall fuel in many industrial plants.

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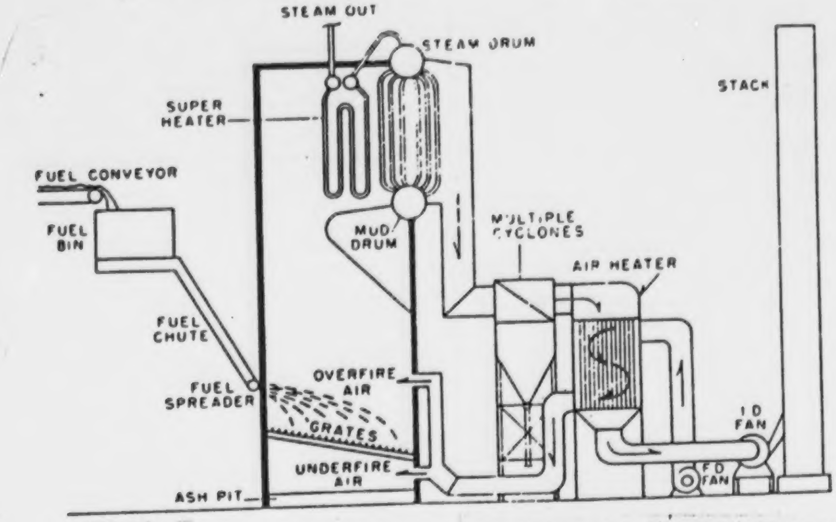
EXHIBIT 7-6: TYPICAL BASIC COMPONENTS OF A BOILER*


STEAM OUT
STEAM DRUM
STACK
SUPER HEATER
FUEL CONVEYOR
FUEL BIN
MUD DRUM
MULTIPLE CYCLONES
AIR HEATER
FUEL CHUTE
FUEL SPREADER
OVERFIRE AIR
GRATES
I D FAN
UNDERFIRE AIR
F D FAN
ASH PIT

*Source: Southwide Energy Committtee, the Forester's Wood Energy Handbook (Report 80-A-12; American Pulpwood Association, Southern Division Office, April 1980).

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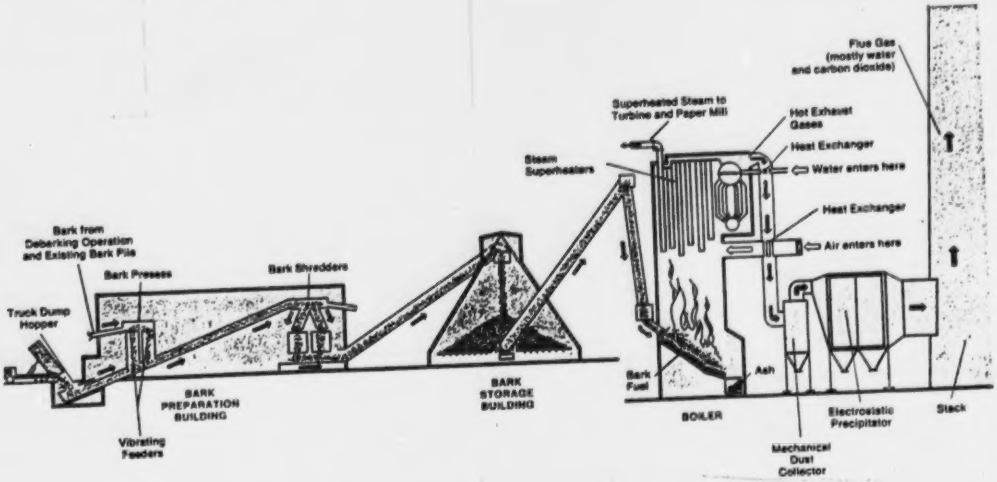
EXHIBIT 7-7: THE BARK BURNING BOILER AT EAST MILLINOCKET*


Flue Gas (mostly water and carbon dioxide)
Superheated Steam to Turbine and Paper Mill
Hot Exhaust Gases
Heat Exchanger
Water enters here
Steam Superheaters
Heat Exchanger
Air enters here
Bark from Debarking Operation and Existing Bark Pile
Bark Presses
Bark Shredders
Truck Dump Hopper
Bark Fuel
Ash
BARK PREPARATION BUILDING
BARK STORAGE BUILDING
BOILER
Electrostatic Precipitator
Stack
Vibrating Feeders
Mechanical Dust Collector

*Source: 1979 Annual Report and 10K, Great Northern Nekoosa Corporation, Stamford, Connecticut, 1980, p. 7.

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He points out that "wood waste and whole tree chips are less costly than oil, natural gas, and coal for boilers above 50,000 pounds of steam per hour. Below this size only a gasifier purchased with a gas/oil boiler is less costly than natural gas, but wood waste and whole tree chips are still more economical than oil. Densified wood is less costly than oil but only for boilers above 75,000 pounds per hour of steam, and more research is needed to cut the cost of densification to make this process viable." (6) Readers are cautioned to keep in mind that the future price structure of all these factors is uncertain.

GASIFICATION

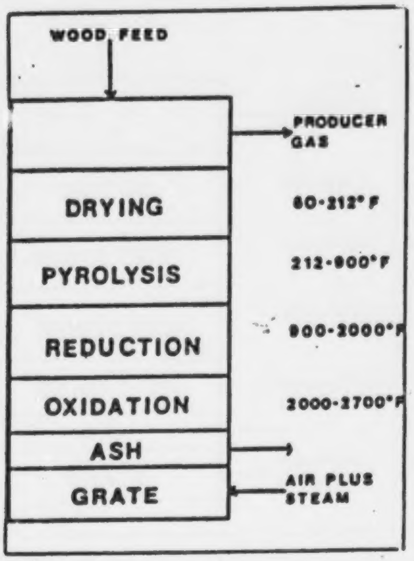
Gasification, one of the thermochemical processes, is a technology going back to the middle of the last century. It was designed originally as a way of converting dirty, solid fuels, like coke and coal, into clean-burning, high-grade gaseous fuels. In the early part of the present century, 1926, about 11,000 gas producers run on coal were in operation in the United States. Four air-blown producers with a capacity of 240 million btu's per hour were constructed in India in 1937. This was the largest facility ever built. "Town gas," also known as "carburetered blue water gas" was very popular throughout the United States before natural gas took over. Wood gas was used during World War II for operating some 700,000 automobiles -- portable conversion of wood blocks or charcoal into gas-fired fuels. The technology is known and proven. However, it is the economics and potential for new technological improvements that may bring gasification back in a big way.

The gasification processes are complex, involving multi-stages within a single reactor. (See Exhibit 7-8) In one design, wood feed comes in the bottom, and a series of processes occur at different temperature regimes in the gasifier. Drying, pyrolysis, reduction, and oxidation produce varying mixtures of carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). The details and alternative choices merit no attention in this report.

It is worth noting that gasification technology is an active area of industrial development. Thomas F. McGowan of Georgia Tech reports that "More than 30 companies and research organizations are working on wood gasifiers in the U. S. at this time." (7)

While chemical physical processes are themselves complex, the gasifier is a simple, well-established, straightforward technology whose value and practicality is established beyond doubt. Virtually any organic material may be gasified -- by no means is it limited to wood or wood waste. Agricultural waste and any other organic material may be so processed, so the universality of the tool, again, adds to its appeal. A principal use of the gasification is to produce what is called low or medium btu gas. These gases may then, in turn, be used directly as a source of heat, or they may be upgraded. The process is one of incomplete oxidation in the presence of controlled amounts of air which leads to low btu gas, or in the presence of controlled amounts of oxygen, to produce medium btu gas. Many organizations, including the Institute for Gas Technology, have a continuing

EXHIBIT 7-8: GASIFICATION


WOOD FEED
PRODUCER GAS
DRYING
60-212°F
PYROLYSIS
212-900°F
REDUCTION
900-2000°F
OXIDATION
2000-2700°F
ASH
GRATE
AIR PLUS STEAM

Reaction zones for an updraft gasifier.

CHEMICAL REACTIONS

Reaction	Heat of reaction, Btu/lb-mole	
Oxidation of Carbon $CO + O_2 = CO_2$	174,600	(1)
Reduction of Carbon (Boudouard Reaction) $C + CO_2 = 2CO$	− 70,200	(2)
Water gas reaction $C + H_2O = H_2 + CO$	− 70,900	(3)
Water gas shift reaction $CO + H_2O = H_2 + CO_2$	− 700	(4)
Methane generation (simplified) $C + H_2 = CH_4$	+ 36,800	(5)

*Source: McGowan, Thomas F., "Gasification Potential Good for Industry," Southern Pulp and Paper, Vol. 44, No. 1, January 1981, pp. 24-27.

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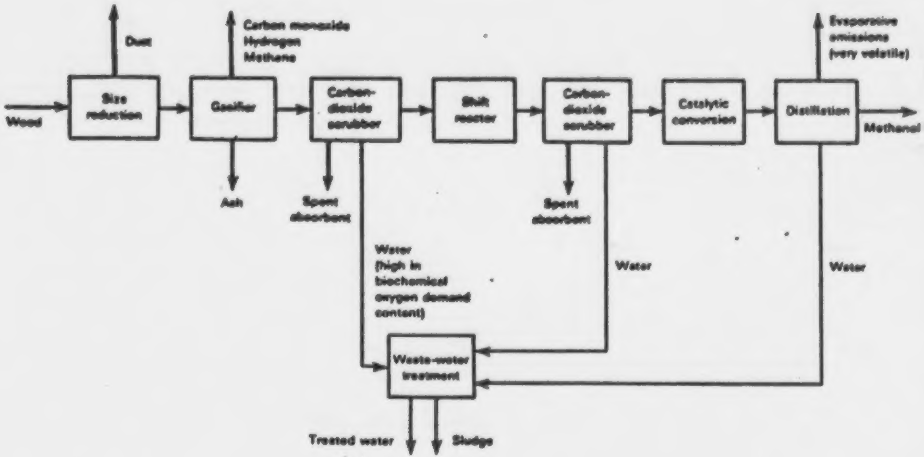
interest in gasification technology as a means not only of dealing with biomass and organic solid wastes, but as a complementary means of supplying gas to the gas pipeline business. For larger facilities, it is feasible to use oxygen to produce the higher quality synthesis gas, medium btu gas. For smaller operations, it is less practical. (8)

METHANOL FROM WOOD

Methanol is a high-volume, well-established article of commerce in the chemical industry. Approximately a billion gallons are produced annually in the United States by well-established chemical processes. (See Exhibit 7-9)

EXHIBIT 7-9: PROCESS FLOW SCHEME FOR THE CONVERSION OF WOOD TO METHANOL, VIA GASIFICATION*


Wood
Size reduction
Dust
Gasifier
Carbon monoxide
Hydrogen
Methane
Ash
Carbon-dioxide scrubber
Spent absorbent
Water (high in biochemical oxygen demand content)
Shift reactor
Carbon-dioxide scrubber
Spent absorbent
Water
Catalytic conversion
Distillation
Evaporative emissions (very volatile)
Methanol
Water
Waste-water treatment
Treated water
Sludge

*Source: Energy Technologies and the Environment," U.S. Dept. of Energy, DOE/EV/74010-1, December 1980, pp. 14-11.

The production is in two stages. The first is the formation of synthesis gas, that is, gas high in carbon monoxide and hydrogen, produced by the partial oxidation of carbonaceous fuel with oxygen. In the second state, the synthesis gas is adjusted with carbon dioxide to achieve a proper ratio for the process. The mixture is then compressed to about 300 atmospheres, and methanol is synthesized. The present commercial processes rely on natural gas as a feedstock. Coal is the most likely new commercial feedstock. Wood can, without question, be used as a basis for methanol production. This has been extensively analyzed in a recent Mitre Corporation report. (9) In using wood, the first stage in the preparation of synthesis gas would involve wood gasification, but simply because methanol by this route has not been a well-established commercial technology, further research is needed to optimize that process. There is no doubt that it would work, however. The economics of pressurized reactions, the economics of competing with alternative sources of methanol drive toward relatively large-sized plants and imply forest facilities resembling an energy farm. However, as we see it, the critical limitation on the production of methanol from wood is not the process or the inter-fuel competition with methanol from coal. The big problem is the intended final use. The ultimate use of the methanol would be as a fuel substitute for gasoline in the transportation sector. The environmental consequences of the direct combustion of methanol in automobiles is so uncertain and fraught with potential dangers that before any serious consideration can be given to the environmental effects of methanol production from wood, one would have to nail down the implications of the use of methanol as a transportation fuel. Furthermore, it is unlikely that any one would have any serious industrial interest in methanol for vehicle fuel until the environmental questions about its use end had been fully addressed.

Our conclusion is in sharp contrast with a recent DOE study which found:

> "Ethanol and methanol, either neat or as blended fuels, have a high probability of achieving environmental acceptability. The environmental concerns associated with the use of these fuels include potential impacts on health and safety or local ecosystems. However, control techniques are available. With proper controls, waste management, and biomass collection techniques, most of the effects are expected to be limited. The producers, distributors, and handlers of ethanol and methanol fuels may also be subject to some occupational hazards." (10)

Also see pages 124-25.

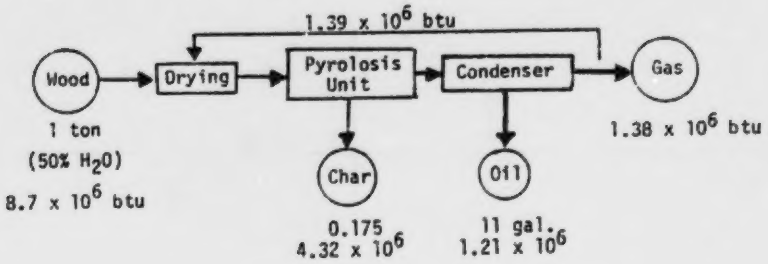
PYROLYSIS

Pyrolysis is another thermochemical process for conversion of wood or other biomass. It involves the decomposition of the biomass in a very low oxygen or oxygen-starved environment. The temperature of the reactor is much lower (500^{o}C) than in gasification. Professor O'Neil of Georgia Tech has provided an excellent description of the process and its potential. The rest of this section on pyrolysis draws upon his work. (11)

A flow diagram of a modern pyrolysis process is presented in Exhibit 7-10 and is accompanied by a mass and energy balance. Unlike the early "destructive distillation" processes, modern pyrolysis processes are highly efficient in terms of conversion to energy and product recovery. Efficiencies in excess of 90% are achieved, based on the incoming dry biomass energy content.

Biofuels are produced from wood by pyrolysis in three forms: a carbonaceous "char", an "oil", and a low-btu gas. The latter may be of medium-BTU rating if oxygen or indirect heating is used.

EXHIBIT 7-10: PYROLYSIS*



*Source: O'Neil, Daniel J., Wood Biomass for Energy, Georgia Institute of Technology, Atlanta, Georgia, 1980.

Invited paper presented at the Southern Forest Range and Pasture Symposium, New Orleans, March 13-14, 1980.

The process is normally operated in a manner to maximize the yields at the solid fuel (char) and liquid fuel (oil) products. Depending on process type and temperature, oil yields can be manipulated in a range of 1-40% and char yields in the range of 10-40%. Approximately 65-70% of the energy content of the dry input feed is recovered in the char and oil fractions. The gaseous product is generally used to dry the wet feedstock.

The char product is an exceptionally good fuel, possessing a heating value of 12,000-13,500 btu/lb. and being of low-ash and low-sulphur content. It can be used for the manufacture of charcoal briquettes or, potentially, a higher valued commodity--activated charcoal.

The pyrolytic oil is a complex mixture of mainly oxygenated organic compounds. It can achieve heating values of 10,000-12,000 btu/lb. In some processes it contains 10-15% water in a stable emulsion which facilitates combustion. It can be burned in combustion with the char or coal as a slurry, as well. Additionally, the oil has promise as a chemical feedback.

The low-btu gas (150 btu/scf) must be used on-site. A portion of the gas is used, logically, for drying the input feed while the remainder may be used for firing boilers or even internal combustion engines.

O'Neil sees pyrolysis as a likely candidate for commercialization in the next decade in those industries where large quantities of forestry and agricultural residues are produced.

Having examined the industrial processes for the use of wood as biomass, let us now turn to residential and small-scale commercial heating with wood. Since the processes for residential and small-scale are basically the same and involve the same kinds of environmental impacts, the discussion will concentrate on residential heating.

RESIDENTIAL HEATING WITH WOOD

There are three ways to directly heat a house with wood:

- o fireplace;
- o stove;
- o central heating.

Until quite recently the fireplace, in most of urban America and to an increasing extent in rural America, was an ornament, a convenience, and perhaps even a bit of cozy nostalgia. It certainly was not an effective or efficient way of heating space. The basic difficulty with the standard fireplace is that it is inefficient. In order to keep smoke out of the residence, an upward draft must draw air from the residence into the fireplace and carry hot air up the chimney. Consequently, the fireplace increases the ventilation of the house by drawing cold air in from the outdoors, through cracks, and up from the basement. Ironically, if one insulates or seals the house to reduce air leaks, that will choke the fireplace and force smoke into the room. The fact is that most of the heat from burning wood goes up the stack. The efficiency of a fireplace may vary up to as high as 10%, but as often as not it may be operating at a net loss of heat.

The stove is usually a free-standing device away from the walls of the room or rooms to be heated. It is either connected to a fireplace chimney or has its own flue, that is, its own separate exhaust going through a hole in the side of the house. The stove has two advantages. By standing in the room it radiates far more of its heat into the room. Second, by being closed, the flow of air through it can be adjusted in such a way as to greatly increase the efficiency of the use of fuel. A good stove may operate at over 50% efficiency and require attention only two or three times a day.

Central heating implies a larger investment and, hence, a more effective and efficient use of fuel. A modern wood-burning furnace could also be equipped with a backup capability to burn coal. The wood for such an automatic central heating system may also have in the most modern versions automatic stokers, automatic loading, and use pelletized or extruded wood. Modern heaters can also be tied to existing central heating systems. This gives the advantage of retrofit and flexibility.

Costs

There are 10 million fireplace installations already in place in the United States. Therefore, the costs are zero except for maintenance -- annual or biannual cleaning. There are about an equivalent number of stoves -- 7.7 million -- with another million and a half being sold each year at a cost of anywhere from $50 to $1,000. A central heating plant, working on wood, would be anywhere from $1,000 to $5,000. The market was down 25 - 50% in the winter of 1980-81. It is too early to tell whether this is a trend or a fluctuation.

In terms of fuel and operating expenses, a cord of wood varies quite widely with the region of the country, and locally for urban, suburban, or rural delivery. The price can vary from \$50 to \$250 at 1980 prices. A cord of wood, depending on its age, type, etc., is good for about \$9 per million btu's based on a 50% efficiency, and 22 million btu's per cord at \$100 per cord. For comparison, a fuel oil at \$1 per gallon -- 130,000 btu's per gallon at 70% efficiency -- would run \$7.70 per million btu's. (13)

Drawing upon some recent work by the Mitre Corporation, in the Northeast United States it would take about four cords -- 88 million btu's -- of wood per season. This is the equivalent of about eight acres of wood-producing forests in the Northeast.

The big market for stoves, fireplaces, and even central heating has been in rural America. According to a Booz, Allen, and Hamilton study, some 20 million families live in rural areas in states which are heavy in wood resources. They estimate that 10 to 15 million homes could eventually become partial or total wood users compared to the present 7.7 million. This would raise the consumption to two or three times the present 0.4 quads (19 million cords) of wood. Recently a wood stove has become a popular item in urban areas -- as a selling point for new condos, as a symbol of independence from the big energy companies, or as a return to the rustic life and even as an economical means of heating.

Home Heating Costs

When an efficient system is used, the economics of residential heating can be attractive. For example, one cord of wood (@ 21 million btu/cord) when burned in a woodstove (50% efficiency) will yield heat equivalent to the following energy sources (13):

One Cord Wood = 1.1 ton Coal
= 115 gallons No. 2 Fuel Oil
= 14,000 cu. ft. Natural Gas
= 3,074 KWH Electricity

Equivalent Costs
Electricity

3074 KWH @ .044/KWH = \$123.00

Cord Wood \$123.00 is competitive

In Fireplace
10% efficient - Wood must be \$25.00/cord or less to compete
Equivalent of 1 cord is 15,616 KWH

The most energy-efficient and cost-efficient practices for the stove owner are not necessarily the most environmentally safe. All types of wood burning technology are in the process of being adapted to modern needs which include low emissions technology. But we are still in the process of catch-up to make modern new stove designs which combine efficiency with environmental soundness. The environmental effects are discussed in the next section.

SUMMARY

The most significant uses of wood energy over the next two decades are likely to be:

- in the forest products industry
- in central power stations outside the forest products industry
- residential and small commercial direct combustion in fireplaces, stoves, and furnaces for space heating or hot water
- gasification in small facilities for immediate or highly localized use
- gasification in large facilities to provide a substitute for natural gas in pipelines
- pyrolysis is a much lower likelihood use

The most significant conversion technologies reflecting those uses are:

- direct combustion in homes and small commercial establishments
- direct combustion in boilers
- airblown gasification

With that, let us turn now to the impacts of these high probability technological developments in the next section.

SECTION 8

THE IMPACTS OF MORE EXTENSIVE USE OF WOOD FOR ENERGY

PREVIEW

This Section deals with the principal effects on human health and safety, the biota and the technoeconomy should there be a big (2 to 5 fold) increase in the use of wood as an energy source. The first part discusses the underlying search for impacts important to EPA. The next part presents an overall map of important impacts. The rest of the section fleshes out the arguments for those impacts.

There are two most important impact areas which merit a substantial research effort. First on the production side, are the effects on forests of cutting and harvesting. Second is the risks to human health from household residential and small-scale commercial burning creating highly localized air pollution pockets. All other effects are either well within the scope of present analysis, identification, and control, or so contingent on research and development and implementation of the techniques as to allow adequate time for detailed research in the future. A critical end use problem with methanol is also emphasized.

INTRODUCTION

The objective of this study is to assist the Environmental Protection Agency in its research on new or newly important environmental problems or opportunities which could become significant over the next decade or two. Understanding and sorting out the likely and possible impacts of wood and other biomass energy on the environment, human health, and safety and the techno-economy is crucial to understanding where anticipatory research could have an especially high payoff. Consequently, dominant criteria for that sorting are problems and opportunities that involve scientific, technological or policy uncertainties which could be resolved by research, field observations, monitoring or other study instruments appropriate to EPA. A second principle has to do with identifying those actions of government which if not taken could incur damage to society or which if not taken could result in society being deprived of a potential benefit. These last two points strongly emphasize minimum rather than maximum roles of government. This principle focuses sharply on those actions not likely to be undertaken in a timely or effective way or at all by private institutions.

This section covers what must be done to put the nation in a better posture to cope with its new environmental problems. The focus is not on what could be done; it is not on teasing out the hundreds or thousands of points of uncertainty on the future biomass energy landscape. The purpose of this study is to identify the big issues, recognizing that the details can be taken care of in a more orderly fashion only when we understand the larger matters.

Two practical implications of this approach to impacts are: first, many details will be passed over. We figuratively if not literally wish to study the forest, not the trees. Second, the major and long-term policy relevant research issues are systemic, structural, and not site, time, or plant specific. Such issues are likely to raise questions which do not fit comfortably in the well-established research categories of any agency. One cannot take a long-term major sector, such as biomass energy, which could come to be a fifth of the nation's future energy supply within the lifetime of most readers of this report, and expect to accomplish much by focusing on second, third, and fourth rank questions. The big questions should be enough.

Large numbers of impact areas will be acknowledged or alluded to, only to be thrown into a larger context of what are significant knowledge needs now, for the management of our future.

How to search for the impacts is expanded on in Appendix A. Impacts can generally result from the technology itself; in this case from the direct combustion of wood; they can result from the substitution that the new technology effects, in this case substitutions for imported petroleum or domestic coal on the energy supply side or substitutions for gasoline on the energy use side. And finally, significant impacts may result from the new capabilities implicit in the technology, but not necessarily prominent during its introduction and early expansion. For example, the capability to densify or pelletize wood may expand the geographic market for wood or other biomass, both within the United States and overseas.

It is assumed in this section that the reader is now familiar with background and textual material in Sections 2 through 7. Therefore, few references will be made back to that material.

WHERE POSITIVE AND NEGATIVE IMPACTS ARE LIKELY

One could immediately assign the impacts of the expenditures of wood energy to four aspects of the overall cycle:

- wood production-silviculture
- harvesting
- transportation
- conversion and use in either central power station, intermediate fuel production (gasifiers), process steam or space heating, residential and commercial facilities.

This is a convenient preliminary way in which to organize and understand many of the effects. However, as with all categorizations, it falsifies some key issues. The central issue which it falsifies is the present status of forest management and its capability to cope with a two to five-fold expansion in the use of wood for energy. A conclusion of the report is that forest management should be seen as a branch of applied forest ecology and that the gap between the strongly empirical, trial and error, experience base for forest management and what would be implied by a functioning applied science of terrestrial ecology is enormous. Until the size of that gap is recognized and understood by all stakeholders, we can at best hope to bumble through and at worst run the risk of substantial deterioration.

Multi-functional management does not have a long history, and has been a substantial element in Forest Service planning for only a decade. The multi purpose use of forests while having a long history as a concept and goal does not have a long history as a functioning reality. The knowledge base required to meet that goal lags the need. The evidence for the need for a fresh approach to forest management as applied ecology, will be developed in some detail below. At this point let us pause to earmark the principal problems at the four stages in the production-use cycles for amplification later.

Critical problems in silviculture--The production side of wood energy. It is widely recognized that any big short-term increase in wood energy availability will come from forest residues, unmerchantable wood and materials otherwise now left in the forest. A closely related source will be the culling of wood from old forests which will carry substantial incidental benefit of increasing overall productivity. The longer term and quite different strategy for supply of wood energy is to move toward a positive program of forest management to plant trees more specifically directed at wood energy production with a shorter growth cycle in a more managed approach. These will be stages 4 and 5 in the diagram, page 84. The critical problems, therefore, associated with these moves are:

- the effects on forest nutrients,
- the effects of extensive removal of organic materials, especially the disturbance of humus.

It is universally acknowledged that the organic matter in the forests conserves forest nutrients, natural fertilizers, soil conditions, water stabilizing elements, and so on. In many sites an aggressive harvesting and removal of these materials would increase nutrient leaching and increase rates of water runoff which in turn could increase sedimentation in rivers and in lakes behind dams. The reduced water retention by the forest would wash more nutrients into the water, creating algal bloom, change the water temperature, and make flooding more likely. The complement to this loss of nutrients would be the requirement in heavily managed forests for greater use of nutrients. In the absence of adequately stabilizing organic materials, this could worsen problems associated with increased runoff. Silviculture under intensive management often uses herbicides to clean out underbrush, to encourage woody growth. The effects of these herbicides are themselves the subject of a substantial concern at the moment. Their long-term future should be related to overall strategies of forest management.

Problems in Harvesting

Harvesting can be very severe on the forest floor. In an extensive, fully managed forest the roadways for harvesting might occupy 10 to 20% of the forest terrain. These roadways tend to erode easily. It is possible for them to go back to vegetative cover in the intervals between harvesting cycles. Big equipment, the chippers, the whole tree harvesters, stump remover, and so on, from sheer size affects the terrain severely. Harvesting, therefore, is an episodic trauma which if not worked with the right equipment and not part of a proper reclamation schedule could easily lead to excessive runoff, nutrient loss, erosion, unsightly scars, and other problems.

Transportation as a Source of Problems

Wood, in whatever form, must be removed to the site of use. Transportation will create those problems usually associated with the movements of bulk materials. With large trucks there will be noise, exhaust, and the tendency, which seems to be nearly irresistible, to overload vehicles and hence, to distress highways. This class of problem, once one is out of the immediate environs of the forest, presents no unfamiliar problems.

Use Related Problems

The problems in the use of wood for bioenergy will fall into two categories, those associated with central power stations or other large facilities and those associated with residential and small-scale combustion. The central power station problems are in no way new. There will be the problems of emissions control and ash and waste removal. The use of wood will tend to relieve one or both of these problems compared to oil and coal. There is substantially less sulfur than in either coal or oil. There may be some increase in nitrogen oxides which is fuel dependent, the technology for controlling them is part of the general environmental control problems of central power station management.

Wood ash is likely to have far fewer heavy metals and less toxic and potentially dangerous materials to wash out in the leachate.

Residential combustion in contrast, is the new and growing health and environmental problem. Small-scale wood combustion as a practical matter is less efficient, less well managed, and is done in smaller, cheaper facilities. The operator, usually a homeowner, is less likely to be attentive to efficient use. That inefficiency will aggravate several substantial problems. The most significant of these, potentially, is the high rate of production of POM's (polycyclic organic materials) from the partial combustion of wood. These POM's are rich in carcinogenic and carcinogenic-like materials; they are produced in substantial quantities and carried on smoke particles. Smoke is now recognized as an environmental problem in Aspen, Colorado, where the control of stove and fireplace burning is already a matter of local ordinances. Far less important, simply because it is a question of management control and experience in both design and use, are the risks of fire, and of carbon monoxide poisoning from faulty ventilation.

Some Benefits

Before turning in detail to the data supporting these various propositions, a brief inventory of benefits from wood burning may help to define the situation:

- better forest management and fire control
- enhanced growth rates in partially and fully managed forests
- less sulfur dioxide production
- increased independence from foreign oil import
- greater diversity of fuel choice for large operators (wood or coal or oil or natural gas)
- some greater flexibility for homeowners and small-scale users
- fewer and less toxic by-products to dispose of or to control
- possible improvement in overall global carbon dioxide production.

FOREST MANAGEMENT AS APPLIED ECOLOGY

The law, the scientific and technological literature, the expressed objectives of Federal agencies such as the Forest Service, the acknowledged self interest of the forest products industry and key environmentally oriented interest groups share a common belief that for the long-term future forests must be managed for multiple uses. These uses include commercial and recreational needs, wilderness preservation, habitats for endangered species, river basin water management, preservation of natural wonders and vistas and other general and specific needs. The implicit and often explicit emphasis is on integration, comprehensive planning and management of what is acknowledged by all to be complex. These goals are virtually coincident with what one means by the use of ecological principles. As explained by one of the founders of contemporary ecology, Eugene P. Odum, several concepts are central to ecology:

- In contrast to a reductionist or traditional scientific view which seeks understanding through detailed study of smaller and smaller units or components, ecology emphasizes the synthetic, the integrated, the understanding of the whole in its hierarchical and interrelated connections.
- As smaller elements combine the new larger units develop properties and characteristics that are new or emergent; in other words, the whole cannot be understood simply by understanding the parts. Reciprocally the parts cannot be understood without understanding the whole.
- The flow of energy into, out of, and within an ecological system

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is a key organizing principle in understanding that system. The relationship of this principle to the forests should be quite clear insofar as commercial uses involve substantial withdrawals of energy while fertilization, nutrient, additives, and soil manipulation are some of the energy inputs. (1)

In contrast to these principles, forest management has evolved from quite different objectives motivated by different scientific and economic drivers. Industrial forests have until fairly recently been exploitative, a characteristic of many of the extractive industries in the United States. Only in recent decades has the need for a long-term perspective in simple terms of self-interest swept the industry. The Forest Service and other Federal agencies, are now by law and by the professional ambiance of their staffs committed to multi-functional forest use. As a practical matter, these have been working objectives only for the past decade. The bulk of research is site and material specific and relatively narrow in its framework. The research in forests is overwhelmingly, to use Odum's term, reductionist, rather than holistic.

To clarify terminology, reductionism as a research approach seeks to attack relatively small well-defined, conceptually, narrow parts of a complex system. The expectation is that the accumulated understanding of the elements will add up to an understanding of the whole. In contrast, the holistic approach assumes that there are classes of problems intractable to this build-up strategy which must be approached initially from an integrated perspective. As we see it, some problems are best approached on a piecemeal basis, while some problems can only be approached from an holistic or integrated point of view.

While it cannot be denied that there are plans to move in a more holistic direction, plans are not accomplishment, and while there is even progress, progress is not success. The current strategies for forest management in becoming a branch of applied ecology still have a long way to go. Turning again to Odum, he is sharply critical of the United States' effort in the International Biological Program to study several biomes in an integrated way. (Biomes are ecosystems, such as grasslands, forests, deserts, tundra.) While basically an American concept and contribution, it foundered on the practical difficulties of having disparate investigators from many disciplines and many institutions trying to function holistically.

The fundamental thesis of this part of the report is that if we do not approach forest management as applied ecology, we cannot understand the choices before us, and cannot effectively monitor developments, and cannot effectively plan.

There is no theory of the forest. Without a theory of the forest, we do not have a scientifically sound basis for forest management.

The difference between what we now do by way of research and our conceptual approach to forest matters and what needs to be done is perhaps clarified by analogy with the distinction between psychology and sociology. They are quite distinct sciences. While both deal with people, they take a different unit of study. For the psychologist the individual is the unit of study, for the sociologist the group, the organization or the institution is the unit of study. As it now stands, the knowledge of the forest is analogous to the knowledge of psychology, and we lack the equivalent body of knowledge or theory that would be the analog of sociology. This is what we mean by the theory of forest.

Quite aside from understanding the forest and forest management, the general subject of ecology is in a curious state of development. General concepts such as everything being connected to everything else, the notion that everything goes somewhere, and the view that interactions are often subtle, circuitous, and complex have all become standard parts of our intellectual furnishings. However, when one looks for the body of practical knowledge capable of useful employment as a management technology, one finds enormous gaps. The best and most solid experimental and observational data are on almost trivially small isolated systems and subsystems. A large continuing effort is needed to develop the middle ground of applied and functioning ecology useful to more effective and subtle management of forests and other biomes.

Let us turn now to some details.

Three vignettes, Exhibits 8-1, 8-2, 8-3, drawn from the work of R. H. Waring of the Department of Forest Ecology at Oregon State University, show different aspects of the problem of forest management.

- pine monoculture crops
- short rotations and complete tree harvesting
- the maintenance of corridors of mature trees, particularly along the streams. (2)

The instances cited by Professor Waring illustrate a more systematic and general body of evidence on the inadequacy of forest management. Document after document produced by the Forest Service as stock taking, planning, topical studies make the point always implicitly and often explicitly that the knowledge base and the theory behind forest management is shaky to non-existent. For example, Owen P. Kramer, of the Pacific Northwest Forest and Range Experimental Station, organized a state of knowledge compendium on environmental effects of forest residues management in the Pacific Northwest. The focus was not on energy but much more on forest fires, soil nutrients, esthetics, residues as havens for insects, pests, and disease, and pollution. The possibility of additional fiber, that is, wood for commercial use other than burning, was also acknowledged. The report, which in the present authors' judgment is an excellent document, is an exercise in empiricism.

The attempt to provide guidelines to forest managers, for research and development and for the design for equipment for treating forest residue shows a flux of ideas nicely captured in the authors' preface.

EXHIBIT 8-1

FOREST ECOLOGY
PROBLEM VIGNETTE 1
PINE MONOCULTURE

"At present, annual biomass production by pine in the Piedmont area of the southeastern United States is greater than that realized for any alternative species. Yet, root rots in places already are becoming persistent. In other regions (New Zealand, Australia, South Africa) where similar monocultures were grown for two rotations, yields are decreasing even with improved genetic stock and applications of fertilizers. What might be the cause?

" First, although the total amount of organic matter in the soil is likely to be still increasing, particularly if the site was an abandoned cotton field, the quality is not. The nutrient quality of pine needles is notoriously poor and the resinous components of wood are resistant to decay. A situation may develop where root rots persist on old stumps while additions of fertilizers are leached away or locked up in an unavailable form. The fine organic matter produced below ground breaks down quickly, particularly following clearcutting of the forest as a result of increased surface temperatures, and more available water and oxygen. Above ground, however, acidic needles decay more slowly and contribute little organic matter to the soil. The loss of fine organic matter below ground reduces the capacity of the soil to hold minerals in a form available to plant roots. Without a balance between fast and slow-decaying organic residues, additions of fertilizers may leach away and further speed the loss of the fine soil organic matter. Some log debris if left on site would reduce surface temperatures and erosion while providing cover for insects and other animals that help keep the soils porous and build structure.

"Some small rodents spread certain symbiotic fungi that help pine trees more efficiently take up minerals.

"Litter from most deciduous trees, in contrast to pine, is high in mineral content, decays more quickly but leaves a better residue. Earthworms and other soil organisms are attracted to the richer litter and additionally improve soil structure. Free-living nitrogen-fixing bacteria often thrive in this environment, further improving the situation.

"Since without human intervention, southern pine species are normally replaced by hardwoods, some possibilities exist to rotate crops or to grow nitrogen-fixing species and selected shrubs under more open pine canopies. Leaf litter, particularly that from hardwoods, should not be removed from the site.

"These suggestions are alternatives to balance management policies. They will cure rather than postpone restoring a balance between production and recycling processes in these ecosystems."

EXHIBIT 8-2: FOREST ECOLOGY: PROBLEM VIGNETTE 2
SHORT ROTATION AND COMPLETE HARVESTING

"The annual growth of a forest peaks when the forest canopy first closes. A policy to thin or harvest at this time is not uncommon. Unfortunately, the forest's use of nutrients is also highest at this time, so complete tree harvesting results in a major loss of the available nutrients, exceeding 50% of the pool for some minerals like potassium.

"Because annual wood production actually plateaus for a considerable range of canopy density, a desirable ecological strategy is to thin just before the production rate begins to decrease. For many forests this is at about 60% of the maximum canopy.

"To reduce the frequency of entrance and favor understory development, the canopy should be opened to about 40% of maximum. Wood production will not be reduced and should be maintained over many rotations with occasional resupply of depleted minerals."

EXHIBIT 8-3: FOREST ECOLOGY: PROBLEM VIGNETTE 3
MAINTENANCE OF CORRIDORS OF MATURE TREES

"In some forests, a full canopy requires nearly a century to develop. Some trees only become established under the shade of pioneer species and only reproduce when they dominate the canopy. Any attempt to maintain a genetic diversity thus requires a very long time perspective.

"When a forest develops a multiple canopy, a whole new canopy ecosystem develops which includes species of mosses, lichens, insects and arboreal species of birds and mammals. Generally we think these unimportant except naturalists, but already we learn that some lichens fix nitrogen from the atmosphere and that the animals greatly increase the rate of mineral cycling. Even when large trees die, they serve as refuges for certain symbiotic fungi and seed beds for selected species such as western hemlock.

"This presents us with a good reason for maintaining corridors of diverse tree species as buffer strips adjacent to managed forests. These could maintain genetic diversity and provide habitat for native forest species. Stream corridors are particularly appropriate for this function.

"When large logs fall in streams, they serve as check dams, preventing erosion, and providing refuges for stream organisms. The dams collect debris and hold clean water until fungi and insects can process the material. Downstream the water remains pure and the waste materials flow in a form useful for aquatic life.

"Removing the source of debris dams, or the dams themselves, erodes streams, reducing future opportunities to grow trees or fish in the area downdream. Careful and infrequent selective harvesting in such corridors is essential if their primary functions as genetic reserves and biological refuges are to be preserved.

"Forests may grow wood or other products at relatively constant or highly variable rates. To keep forests from becoming imbalanced we must appreciate the processes that maintain these systems and assure that human manipulations affecting them husband these resources for the benefit of this and future generations."

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> Both the concept and knowledge of the effects of forest residues are in a state of development. The very definition of forest residues has changed during the formulation of the research and development program sponsoring this Compendium. At first, the definition included only slash; now it encompasses both living and dead, mostly unwanted, woody materials that accumulate naturally on the forest floor or are left after timber harvesting. Little research has been conducted to determine the optimum amount of residue needed to maintain or improve soil conditions for best regeneration survival and growth or to present a "natural" appearance. The amounts and kinds of residue that comprise a maximum tolerable fire hazard have not been determined. The effects of alternative residue treatments on the component forest resources such as soil and trees are only partly known. (3)

Robert D. Buckman, the Director of the Experiment Station directly sustains the inadequacy of forest theory when he says in the foreword:

> Considered up to now primarily as the forester's solid waste disposal and potential air pollution problem, residues management affects many facets of forestry.
>
> It is time to take an integrated approach to both research and management of forest residues. In this Compendium we present a foundation of current knowledge on which the research and development work of our Forest Residues Reduction Program, already started, will continue to build. (4)

The skimpiness of concepts underlying forest ecology is revealed in the section of the same report on making decisions "Once the desirable and undesirable impacts of alternative residue treatments have been identified... the manager must determine which trade-offs are most acceptable when all variables are considered." (5) Yet no model, no theory, no paradigm, no algorithm, no overall guidance of a scientific sort is given. The implication is that it is fundamentally a matter of psychological trade-offs.

Forest nutrients are without question the central concern of all interested in maintaining ecological balance within the forest. This was the subject of a recent (1979) conference at the School of Forestry, State University of New York. (6)

The systematic study of forest nutrients started a little over 100 years ago (1876) in Germany. The key element in the importance of nutrient cycling in forest ecosystems has been highlighted by Carl Tamm of Sweden who points out

> It is generally recognized that forest ecosystems usually have an almost closed nutrient cycle and lose less dissolved and particulate matter with runoff water than most other ecosystems...However, the tightness of the forest nutrient cycle varies with a number of factors.

Successional stage, which affects the intensity of uptake by roots and the properties of the humus layer, and net mineralization (or immobilization) in soil.

Water regime (which depends on climate, topography, soil depth, soil texture, vegetation cover). Anaerobic conditions may lead to incomplete decomposition of organic matter and nutrient immobilization in peat.

Weathering and mineralogy, which depend on climate (weathering), parent material, production and quality of litter, and time. Clay minerals formed in the soil or contained in the parent material also affect leaching by absorption or lattice fixation (K^+, NH_4^+).

Input from outside or formation in situ of anions (in particular small ones like NO_3^-, SO_4^{--} (in circumneutral or alkaline soils HCO_3^-), which are easily leached away.

Nitrogen fixation, denitrification.

Input from outside of plant nutrients scarce on the site (e.g. input of NH_4-N and NO_3-N, on ombrogeneous bogs almost all nutrients, etc.).

Input from outside of substances toxic for soil organisms, leading to changes in mineralization and transport processes in the soil.

Removal by harvests of tree crops or other organic substances. (The special subject of the symposium.) (7)

He concludes his review of the state of the field with a strong push for a forest ecosystem's perspective.

> I hope that my presentation, and even more the papers to be presented in this symposium, will make it clear that we have to think in ecosystem terms when we try to judge the impacts of management operations on forest ecosystems. It is particularly important that we do so when the management operations introduced are innovations without long experience. Intensive harvesting, especially if combined with short rotations, is such a new treatment as used on an industrial scale and over large areas. Cases in the past of intensive use of all forest products, such as the litter removal in Europe and some coppicing practices, are not reassuring. On the other hand we now have the means to remediate losses of nutrients by fertilizing or by cultivating nitrogen-fixing species. However, the fact that we now have technical means to change a forest site in different directions, both positive and negative ones, makes it even more imperative that we try to understand what we are doing. (8)

However, the rest of the some 40 papers in the report proceedings are basically exercises in empiricism, empirical modeling, micro approaches. There is not in the whole proceeding, in the present authors' opinion, adequate attention to the forest as a system; again, no theory of the forest and no theory therefore of its nutrients.

The Director of Forestry Research from the Weyerhaeuser Company, George R. Staebler, frames his discussion around biomass as an economic good with value for its content as opposed to its esthetic or cultural values. Even within that relatively constrained framework, he sums up with an urgent message:

> I have attempted to show the off-site values of forest biomass as a raw material for a myriad of products. Those products rank in value from high to low to negative at any point in time, and all products of positive value are removed according to economic laws. As accounting procedures are rationalized, as values increase with changing markets, as new higher value products are developed, and as costs of removal are reduced through technological advances, the amount of biomass removed will increase, often dramatically.
>
> Forest biomass, particularly residuals of low off-site value, has value on-site for its nutrient content and certain other benefits to the regeneration of a new stand. Some characteristics of the residual biomass are detrimental to regeneration and become costs that enhance the economics of removal.
>
> The off-site values of the marginal-value biomass can be, and increasingly are, rigorously evaluated and the evaluation is the basis for the decision to remove or leave.
>
> The on-site values, by way of contrast, are difficult to determine and are largely dependent on advances in the sciences of forest soils, tree nutrition, and forest hydrology. Removing biomass may impair these on-site values and thus are of critical importance in drawing up the final biomass balance sheet.
>
> The message I would leave with you is that the values attachable to tne nutrient cycle, the topic of this symposium, must be quantified and quantified quickly. I urge that we be on with the task. (9)

It would be difficult to see how one could attach values to the elements of the nutrient cycle without a theory of the forest.

Earl Stone of Cornell University, Department of Agronomy, has summarized a number of the recurrent themes with regard to nutrient removal and intensive harvesting.

- What levels of nutrient removal can our soil-forest systems sustain with no or only minor decrease in productive capacity?

What elements will become limiting first in the face of accelerated removals, and how will soils or forest types differ in response?

- How can we objectively predict the nature and magnitude of possible decreases in productivity, and what measures can be devised to avoid or mitigate such decreases, or even to increase productivity?
- What will be the physical consequences, if any, of more frequent traffic by heavy harvesting equipment, and lower returns of organic matter to the soil?
- What unplanned secondary changes are likely as a result of altered nutrient circulation; as for example, in species composition, habitat diversity or pest problems? (10)

Humus

Many of the nutrients essential to the forest ecosystem are disrupted by intensive harvesting. Humus is not a simple fertilizer or merely a vehicle for sustaining nutrients. It is an extremely complex subsystem of the forest. As Hans Jeney of the College of Natural Resources at the University of California, Berkeley, has put it:

> Production of biomass demands suitable combinations of climates and soils. For a soil to function effectively in plant production it must possess substantial water-holding and ion-exchange capacities, good physical structure, and thriving populations of bacteria, fungi, and invertebrates. These attributes are highly correlated with humus substances, which are dark-brown organic macro-molecules rich in phenolic compounds and are derived from plant remains and microbial synthesis. Humus has high sorptive capacity for toxic metals, and its buffering power mitigates the impact of acid rain. Humus maintenance requires a steady influx of plant biomass from root decay and aboveground organic residues. Good soil structure depends on aggregation of colloidal clay platelets held in position by organic threat molecules. These are being consumed continually by invertebrates and have to be replenished by photosynthates and microbial products.
>
> At the turn of the century, farsighted agricultural experiment stations set up permanent cultivation plots and monitored for decades the nitrogen and carbon balances. Stirring soil and removing crops initiated profound declines in nitrogen, carbon, and humus substances and caused deterioration of soil structure. Under these circumstances water infiltration is reduced and runoff and sheet erosion is encouraged. Crop yields suffer. While applications of nitrogen fertilizers boost yields, they have not restored the soil body. In central Europe, farmers used to remove forest litter and put it on their fields for manuring. Tree production declined markedly, documented by

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Aaltonen. Mulches of leaf litter and stubbles of grain crops keep wind erosion under control.

We are promised construction of ingenious machines that will pick up all crop residues in the fields and leaf litter and humus in the forests. The carbon and nitrogen cycles of ecosystems will be curtailed and soil stability endangered. Because of a possible climatic warm-up, we do not wish to accelerate humus oxidation and the concomitant flux of carbon dioxide from soil into the atmosphere.

I am arguing against indiscriminate conversion of biomass and organic wastes to fuels. The humus capital, which is substantial, deserves being maintained because good soils are a national asset. The question will be raised, How much organic matter should be assigned to the soil? No general formula can be given. Soils vary widely in character and quality. Some can endure a measure of organic deprivation, as in overgrazing; others cannot. On slopes, strongly erodible soils, or soils that have been eroded already, require more input than soils on level lands. The Agricultural Experiment Stations, Extension Services, and the Soil Conservation Service possess a pertinent store of knowledge that should be put to use in energy conversions. (11)

Again, one sees that the complexities are beyond the bounds of understanding through reductionism and empiricism; a theory of the forests is called for.

American foresters' participation in international meetings have made it clear that we have an inadequate knowledge base on both the supply of forest resources and the long-term implications of more aggressive harvesting. The 1979 conference at Michigan State University on Man and the Biosphere dealt with the biological and sociological bases for rational use of forest resources for energy and organics. It was sponsored by the Forest Service. Its recommendations on environmental consequences are shown in Exhibit 8-4. (12) While modeling is not coincident with a theory of the forest, it is one tool for moving in that direction. It is rather interesting to see how throughout the global community there is the emphasis reflected in Exhibit 8-4 on more modeling.

Some summary conclusions from the Canadian Forest Service's National Forestry Institute on whole tree removal, the extreme in management, are suggested in the following conclusions from Carlisle's work. (13)

1. The success of using forests on a large scale for energy will ultimately depend upon environmental issues.

2. Conventional roundwood harvest on long rotation does not appear to cause major nutrient depletion, nutrient concentrations in stem tissues being low.

3. Harvesting whole trees means the removal of twig and leaf

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EXHIBIT 8-4

REPORT OF WORKING GROUP *

THE ENVIRONMENTAL CONSEQUENCES OF INTENSIVE FORESTRY AND THE REMOVAL OF WHOLE TREES FROM FORESTS

RECOMMENDATIONS

1. Information on the physical limits of the forest resource and the long-term effects that various uses can be expected to have must be made available to decisionmakers, politicians, and the publics they represent. This may be possible through articles, briefing papers, workshops, or symposia, and should be undertaken jointly with agencies and organizations also dependent on the maintenance of biological productivity.

2. A dynamic model with economic and ecological feedback should be developed for one or more plantations or forests under intensive management for energy.

3. People in developed countries must realize that there is very little potential in tropical regions for production of biomass for energy and organics for export. The production in tropical countries is needed for local consumption.

4. Governments in developing countries should recognize that biomass is an important source of energy, pulp, and other organics. These important uses for wood will increase in the future. Further, governments should recognize the environmental consequences of intensive use of biomass.

5. Governments should carry out ecological land classification surveys to ensure the best utilization of various land types. Governments should increase research on tropical forests to ensure long-term productivity of wood for lumber and fuel and the maintenance of plant and animal genetic resources.

6. There is a need for single or mixed species plantations on degraded land, a need to develop suitable species for plantations, and a need to continue research on agroforestry into more efficient production of food, fodder, and fuel.

7. There is a need to increase research for the utilization of other forms of biomass for energy. For example, increase the efficiency of methods for production of charcoal and biogas, and inform people through extension services.

8. Local people must be involved in planning and establishing plantations so these people participate more directly in the processes and benefits of plantations.

9. Continue research efforts in those ecosystems subject to periodic fires (some deciduous forests and Mediterranean ecosystems) to improve knowledge of when to harvest biomass to avoid loss through wildfires.

10. Encourage governments of developing countries to weigh carefully the short-term benefits of excessive forest exploitation for immediate economic gain against the long-term benefits of forest maintenance for future generations.

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tissues which contain high nutrient concentrations, and account for 28% to 92% of the nitrogen, 20% to 83% of the phosphorus, 6% to 85% of the potassium and 5% to 87% of the calcium in the above ground tree components. Although leaf and twig biomass may be low, these tissues play an important role in the forest nutrient cycle. Engineers and economists tend to regard leaves and branches as wastes. They may be a waste to man but not to the forest.

4. Harvesting whole trees on long rotations may or may not result in a nutrient deficit, depending upon the element and the type of forest. It is impossible to generalize.

5. Highly productive, short rotation (2 to 10 year) systems result in major nutrient deficits, even when the leaves are left on the site. These losses will need to be made if soil fertility is to be maintained. These intensive systems, in which the trees are in the juvenile, nutrient rich stage, are ecologically unstable monocultures requiring major expenditure to maintain. Whether or not costs and benefits will permit major expenditures on soil fertility maintenance (as in agriculture) and protection is still a point in question.

6. It is impossible to generalize about the effects of whole tree harvesting, since impact is site and element specific. Neither can simple conversions be made from stem nutrient content to whole tree content; nutrient concentrations and leaf/twig biomass are too variable. However, a general statement can be made to the effect that shortening rotations greatly increases the risk of serious nutrient depletion.

7. Impact of whole tree harvesting and short rotations is not just a matter of nutrient accounting. A rapidly circulating small amount of nutrients may have more effect on productivity than a slowly circulating large nutrient capital. Magnitude of nutrient losses may be less important than where the losses originate (e.g. in leaves and twigs).

8. Little is known about the effects of whole tree harvest and short rotation forestry on soil organic matter levels, the carbon cycle and associated microorganism activity. In some areas the carbon losses could be of more importance than nutrient losses.

9. Replenishment of soil nutrients depleted by whole tree harvesting and use of short rotations is not just a simple matter of fertilization. Fertilizers are often in an unacceptable form for uptake by the trees, can be leached from the system, are costly in terms of dollars and energy, and must be considered in the overall cost/benefit context.

10. There are major gaps in our knowledge of nutrient input and

output in forest ecosystems. Very little is known about nutrient income in precipitation in Canada or how much is retained in the system, and little is known about income of nutrients to the forest cycle from soil minerals. It is difficult to prepare a full nutrient budget.

11. A great deal of biomass and nutrient concentration data remain unpublished in theses and files which would be invaluable in computation of regression equations for absolute tree nutrient content on diameter necessary for efficient modeling. It is suggested that these data are solicited from scientists and a central data bank established. There is also a need for coordination of nutrient cycle work in North America to avoid any _ad hoc_ approach and duplication of effort.

12. Understanding the real meaning of nutrient and carbon losses due to whole tree harvesting and short rotations is greatly hampered by our lack of understanding of soil processes, particularly in Canada.

13. Monitoring nutrient budgets and soil fertility should be an integral part of intensive forestry management, particularly where short rotations are involved.

14. Labor intensive, high cost measurements of nutrient budgets could be greatly simplified by the development of models which indicate what type of samples and how many should be taken to achieve a particular objective. These models would also assist with identifying information gaps.

15. Assessment of impacts of whole tree harvesting and short rotations is partly a technical problem and partly philosophical. Each impact, and the decision about whether or not it is acceptable, must be considered in the context of forest management objectives, and the kind of forest we wish to establish and maintain.

Three recent studies by the General Accounting Office highlight the inadequacy of forest planning for energy use. There seems to be little disagreement that the Forest Service has done excellent work in meeting forest management needs and has done excellent service in supporting industry needs framed around traditional wood products. Interest in wood biomass for energy highlights, in contrast, inadequacies of the current government approach to forest information, data bases, forest modeling, and the absence of a forest theory. One of these recent GAO reports simply shows the forest accounting scheme is behind the times. That report, "The Nation's Unused Wood Offers Vast Potential Energy and Product Benefits" concludes "while the Forest Service and the Department of Energy have an interest in greater residue use, they have made little progress in developing a national wood residue plan." GAO recommends that the residue assessments be made close to particular end-use facilities and that the assessments include topographical features, transportation corridors, economic hauling, distances, and landowner attitudes. (14)

Another GAO study dealing with the question of the extent to which herbicide should be used on forest land nicely illustrates limitations on the knowledge of effective forest management. Herbicides have been routinely used in forest management at several stages of silviculture:

- site preparation before planting
- stand maintenance, usually during the first 10 years of growth
- pre-commercial thinning, usually done 10 to 15 years into growth
- commercial thinning at various intervals, usually after at least 20 years of growth.

Our point in discussing the GAO work on herbicides is not to at all address the question as to the value, the safety or the utility of these herbicides, but only to point out that the GAO found:

> None of the Bureau districts or Service forests visited consistently gathered and documented site-specific pretreatment information or consistently evaluated the various treatment methods used. Such information is needed so that management can not only evaluate its decisions but also compare successful projects with failures to determine why particular methods work in some areas but not in others.
>
> Currently, no standard, objective criteria exist for deciding whether a stand of trees should be released. The criteria used varied from forest to forest and within forests. (15)

The results again suggest the absence of a theory of the forest. The Forest Service over the years has been basically oriented toward eventual industrial uses not energy use. As already cited (Section 6) the OTA has pointed out the commercial orientation of the Forest Service has led to underestimation of wood residues and hence, wood available for energy.

Rene Dubos has perhaps best hit on the theme of what would be implied by both contemporary needs and the existence of an adequate theory of the forest.

> The earth is to be seen neither as an ecosystem to be preserved unchanged nor as a quarry to be exploited for selfish and short-range economic reasons, but as a garden to be cultivated for the development of its own potentialities... (16)

The above presentation of material on forest management and the need for a push to applied ecology has relied on extensive quotes from major studies and conference reports. The reason for this is two-fold. Within the scope of the present effort, it would not be practical to put together a monograph synthesizing all that material to lay out all the evidence systematically. It seemed appropriate, however, to draw upon the deliberative conclusions of

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the numerous studies cited, which collectively converge on the single message, we have a long way yet to go in developing a practical useful theory of the forest, and a system of applied forest ecology.

A SUMMARY OF POTENTIAL ENVIRONMENTAL IMPACTS OF WOOD ENERGY DEVELOPMENT

The potential impacts of a two-to-five-fold increase in the use of wood for energy are so numerous and so contingent on policy, economic, technological, and management developments that it seems best to present a general listing of those potential effects (Exhibits 8-5, 7, 8, 9, 10, 13) as context and then to discuss those which seem critical and have high relevance to EPA's mission. While hundreds of analytical and research and study projects could be deduced from the material in these exhibits, the strategy here is to identify those which should have strong impact on policy management or technological development in relation to the environment, health and safety.

The materials for these tables are drawn from all sources used in the study. No single source is outstanding or particularly convincing in highlighting one or another item, and hence, repetitive attributions and citations are omitted. Where appropriate, citations are given in the discussion. General goal sources have been reports from Mitre (17), OTA (18), DOE (19) and EPA (20).

Air

Exhibit 8-5, effects on air, reflects the general agreement that there will be benefits in reducing acid rain production, particularly in the Northeast. At the global level, there may be the improvements in net carbon dioxide input to the atmosphere. At the local level, there may be increased air pollution from expanded aerial application of pesticides, fertilizers and fire retardants. There may be highly localized dust contamination from roads, skid trails and local transportation. There will be substantial production of particulates in smoke from residential and small scale wood combustion. That is discussed in detail below as the potential major new health risk. There are relatively few and readily controllable, air pollution problems from central power station use. There are likely to be fewer forest fires and less open burning of forest and mill residues. (21) Indoor pollution may become more of a problem; and wind may increase, particularly in those areas where windrows, as in the Midwest, are being cut down for firewood.

Exhibit 8-6 summarizes the uncontrolled emissions from wood in comparison with goal, gas and oil.

Water

Potential water effects are shown in Exhibit 8-7. As with most of the wood related effects, they are largely driven by issues of forest management. The central questions of nutrient runoff and sedimentation have been discussed under the general question of forest management. The trace metals from ash piles and the trace materials from wood chip bleaching are questions that are fully manageable at the conversion plant. That, however, does not imply that good management will prevail.

Water availability conflicts could become significant, particularly in the case of highly managed forests where the movement is to control the inputs of pesticides, herbicides, and water.

Soil Runoff

Soil runoff is a land and water problem. David Pimentel, et al. have recently reviewed biomass energy from crops and forest residues and point out that "roadways used to obtain timber and pulpwood account for about 90% of the soil erosion problems associated with harvesting forests. The erosion is generally severe; soil losses range from 0-01 to 3-9 tons per hectare per year. The accelerated surface erosion due to roads would continue for only two to six years if regrowth vegetation were allowed on the roads, skidways, and landings after harvest." They conclude that investigations of soil degradation problems should be carried out before any large-scale biomass energy is adopted. Related to research needs is the new Soil and Resources Act requiring Federal agencies to renew their policies to encourage soil conservation. They go on to state "...with current crop and forest management practices such developments (biomass energy) would only add to environmental problems associated with soil loss and land degradation." (22)

E. W. Hall in an excellent review and comparison of environmental effects of fossil and wood fuels (23) summed up the nutrient situation as follows:

- Forests remove definable amounts of nutrients from the soil. The rate of removal is dependent on: (1) species; (2) stocking; (3) age of the stand; (4) available moisture; (5) soil nutrient availability.
- The amount of nutrients removed from a site, due to silvicultural practices, varies with the practice and the variables mentioned in conclusion 1.
- The effect of nutrient removal, by harvest, is not known at this time. Available data are site specific and are not amenable to comparisons or projections.
- Nutrient inputs to forests are variable and are not yet fully quantifiable.
- Forest fertilization practices could serve as a source of nutrients. However, fertilization suggests good forest management. Due to the land ownership patterns in Vermont, fertilization may not be feasible on state lands.

Forest Ecosystems

Ecological effects are, of course, central to all other effects associated with the increased use of wood energy. This was discussed in the earlier section as forest management as applied ecology. Exhibit 8-8 suggests some of these concerns.

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EXHIBIT 8-5: POTENTIAL ENVIRONMENTAL IMPACTS OF WOOD ENERGY DEVELOPMENT

AIR POLLUTION

- Gaseous residuals from thermochemical biomass conversion
  - -- net carbon dioxide down compared to fossil fuels
  - -- sulfur dioxides down
  - -- NO_x up
- Fugitive dust from roads and skid trails
- Emissions from harvesting and transport equipment
- Effects on atmospheric CO_2 concentrations globally may be helped
- New kinds of air pollution or newly significant quantities, e.g. polycyclics from wood
- Particulate air pollution from residential and small scale burning
- Aerial application of pesticides, fertilizers, and fire retardants
- Fewer forest fires
- Less open burning of residues
- Wind increase
- Indoor air pollution up

EXHIBIT 8-6: UNCONTROLLED EMISSION FACTORS FOR WOOD, COAL, GAS AND OIL COMBUSTION (In pounds per million BTUs) **

FUEL/POLLUTANT	PARTICULATES	SO_x	CO	HYDROCARBONS	NO_x
WOOD	0.4-3.0	NA	26	NA	NA
Small stove	0.4-3.0	NA	26	NA	NA
Fireplace	2.0	0	12	0.5	0.1
COAL*	0.8	1.52	0.4	0.12	0.24
GAS*	0.005-0.014	0.0005	0.018	0.007	0.073
OIL*	0.17	1.98	0.34	0.007	0.124

Source: Calculations based on emissions factors given in Compilation of Air Pollutant Emissions Factors, Environmental Protection Agency (AP-42).

Fuel Characteristics Assumed:

Wood = 4,250 BTU/lb, 1% ash, 0.1% sulphur
Oil = 145,000 BTU/gal, 0.7% ash, 2% sulphur
Coal = 12,500 BTU/lb, 10% ash, 1% sulphur
Natural gas = 1,100 BTU/ft^3, sulphur = 2,000 gr/10^6 stdft^3

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* For residential heating equipment

** Jones, Martin. Energy from Biomass: The Implications of Residential Heating with Wood, Vol. 5, Report MP-81W7 for National Science Foundation (Mitre Corporation/Metrik Division, McLean, Va., December 1980, p. 24).

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EXHIBIT 8-7: POTENTIAL ENVIRONMENTAL IMPACTS OF WOOD ENERGY DEVELOPMENT

WATER

- Sediment, dust and nutrient loads from runoff
- Liquid and solid residuals from thermochemical biomass conversion
    - phenols
    - leachates
    - low-molecular weight oils
- Disposal of sludge after anerobic digestion or fermentation
    - salts
- Increased silting at dams
- Clogging of streams from logging residue more or less possible
- Leaching of nutrients into surface and groundwaters
- Eutrophication
- Improved water management
- Herbicide-pesticide pollution from runoff and aerial application
- Warming of streams
- Trace metals leaching from ash piles
- Organic leaching from wood chip piles (BOD up)
- Water availability conflicts
- Drinking water contamination and taste changes

EXHIBIT 8-8: POTENTIAL ENVIRONMENTAL IMPACTS OF WOOD ENERGY DEVELOPMENT

FOREST ECOLOGY AND BIOTA

- Depletion of soil organic content due to residue removal
    - effect on microorganisms
- Soil changes, humus, nutrients, structure, microflora
- Changes in wildlife
- Aquatic ecosystems
- Change in forest type -- often a goal
- Genetically homogeneous forest crops, benefits and risks in terms of productivity, susceptibility to pests, disease, etc.
- Better forest management
- Worse forest management
- Esthetic and visual changes
- Reduced fire hazards
- Multiple or single purpose forests
- Poaching

Curiously enough, the principal risk is also the potential source of the most significant benefit. The principal risk is that we will over-exploit, mismanage, and create what amounts to irreversible, or very slowly and expensively reversible, mass environmental damage. That damage can come from stripping away forests, removing nutrients, creating floods, creating soil runoff, and silting of rivers and dams. It can even lead to changes in aquifers, i.e., the drying up of underground water supplies. The reciprocal of this doom and gloom is that the growing awareness of these major risks from the large scale energy harvesting from forests may lead us directly and immediately into more comprehensive and integrated forest management, a new level of systematic understanding of forest ecologies.

Poaching is a particularly interesting question that poses one of the worst forms of poor management. It can lead to loss of valuable large or small stands, upset planning, and bring to the forest products industry a new black market and a certain degree of violence. Poaching might cause revocation of free use of national forest permits and promote more regulation and intervention at the local level. It could, in fact, even bring organized crime into forest operations, as has been alleged already to have happened in the Northeast.

Land Effects

The effects on land are intimately tied to the forest ecology question and basically relate to the knowledge base and the strategies for forest management. The big risks are seen in removal or organics, nutrients, and humus, from overworking of the soil and too aggressive and complete harvesting. Erosion from highways, heavy vehicles, trails, general disruption of the quality of the land is well known as a problem. Obviously, specific situations could make the matters worse such as harvesting on slopes. Other land problems have to do with the transportation requirements for large scale wood use. It is not completely clear that there would be problems not already well known in the industry. There may also be uses of pesticides, fertilizers, and other adjutants to an extent to create land and runoff problems. And, finally, the application of sludges to the forest may prove to be technically and economically plausible. Its effects and mode of application are unclear. (Exhibit 8-9)

Health and Safety

Without question, logging is a dangerous occupation. (Exhibits 8-10, 11) As logging and harvesting for wood energy increase, we can expect increases in injury and death, and perhaps even greater than proportional increases because much of the new labor force will be inexperienced. There is a high likelihood of injuries and deaths from amateurs and part-timers harvesting for residential or small local use. Internal injuries may be only a transition period. As we move to larger scale management of larger plots of a better ecological base, the workers themselves may have less immediate contact with the dangerous tools and may be using larger, heavier, more remote and safer equipment. Logging is now made up of small businessmen. The average company has 2-3 employees and harvests 37.5 cords per week or 11.3 cords per person week. A small crew working with modern machines can harvest 35-50 cords per day (24).

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POTENTIAL ENVIRONMENTAL IMPACT OF WOOD ENERGY DEVELOPMENT

EXHIBIT 8-9

LAND

- Depletion of soil organic content due to residue removal
- Disposal of ash and char residue after thermochemical biomass conversion
- Compaction of soils
- Surface erosion
- Loss of some long-term water storage capacity of forest
- Possible loss of forest to alternative uses
- Changes in soil quality/nutrient
- Better land management
- Slumps and landslides
- Overexploitation of forest
- New institutional management mechanisms
- Marginal land brought into use
- Competition for land use
- Overharvesting on slopes
- Trails and roads resulting in high erosion
- Transportation problem unclear
- Overuse of pesticides, fertilizers, etc.
- Sludge in the forest for fertilizer

EXHIBIT 8-10

HEALTH AND SAFETY

- Gaseous, liquid, and solid residuals from thermochemical biomass conversion
  - hydrogen sulfide
  - carbon dioxide
  - carbon disulfide
  - sulfur oxides
  - cyanide
  - nitrogen oxides
  - ammonia
  - tar and oil produce
- Health of energy plantation workers
- Increase in occupational risks in proportion to new entries into the work force
- New, poorly understood health and safety risks
- Noise
- Methanol - in end use - in automobiles
- Increased worker injury and death in harvesting, especially among amateurs
- Residential air pollution sources
- Risk from burning inappropriate combustibles in home, e.g. scrapwood, crank case oil, treated lumber
- Scalds, burns, fires at home
- Reduced occupational hazards more biomass substitution for coal, etc. of less black lung
- Reduce air pollution risks from reduced SO_2

EXHIBIT 8-11: OCCUPATIONAL INJURY AND ILLNESS RATES, 1976[a] *

	1976 annual average employment (in thousands)	Total cases[b] per 100 full-time workers	Lost workday cases per 100 full-time workers	Total cases[b] per Quad produced	Lost workday cases per Quad produced	Average number of days lost per lost workday case
Private sector (all industries)[c]	64,690	9	4	—	—	17
Forestry	11	13	5	—	—	21
Logging	84	25	14	—	—	—
Total lumber and wood products[d]	677	22	10	28	12	17
Bituminous coal mining	224	13	8	2	1	25
Oil and gas	345	13	6	1	0.5	45

a) These figures only include the occupational injuries that are reported: the numbers in some sectors are actually higher because of unreported accidents; b) includes fatalities, c) excludes farms with fewer than 11 employees; d) includes logging.

*U.S. Congress, Office of Technology Assessment. Energy from Biological Sources, Vol. 1 (U.S. Government Printing Office, Washington, D.C. July, 1980). Page 85.

After Bureau of Labor Statistics, Chartbook on Occupational Injuries and Illness in 1976. Washington, D.C.: U.S. Department of Labor, Report 535 (1978), and Office of Technology Assessment.

To what extent there will be reduced health problems from substitution for coal and hence reduced incidence of black lung, and of sulfur dioxide air pollution are conjectural. We find two dominant potential health problems from increased use of wood. One is methanol in its end use in the automobile. The clarification of the understanding of that problem overrides all other problems associated with the methanol fuel cycle. Methanol demands close attention. (See below) The second health and safety effect is that the residential use end, particularly framed around the problem of POMs (polycyclic organic materials) produced with smoke from partial combustion. The central issue is to what extent POMs are likely to be responsible for cancer or other diseases. POMs are discussed in a later section.

Methanol

The recent Department of Energy Environmental Information Handbook entitled "Energy Technologies and the Environment," December 1980, has nicely summarized the environmental issues at the end use of methanol. The summary of the situation is so complete and succinct that it is presented in toto in Exhibit 8-12. We emphasize their conclusion that "more research is needed to characterize the long term effects of chronic methanol inhalation." We further add that the general question of automobile methanol emissions must take into account the percentage of automobiles grossly out of tune, with highly inefficient carburetion, and emitting large amounts of uncombusted fuel. Automobiles emitting gasoline can be smelled in any parking lot. Equivalent levels of methanol could be dangerous. We see that it is essential that practical knowledge, not laboratory standards developed around the gasoline problems, be brought to bear on understanding the methanol issues. If we wait until methanol is widely marketed and backed by big investments it will be extremely difficult to accept bad news. Now is the time to determine how bad, if bad at all, that news could be. While the standards vary and the surveys are limited, surveys to date suggest that 18 to 30% of automobiles are out of

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EXHIBIT 8-12

METHANOL-AN END USE HEALTH RISK

Neat methanol is an exceptionally clean-burning fuel. It produces no particulate matter, no polycyclic aromatic hydrocarbons, and no sulfur dioxides. It yields less nitrogen oxides than gasoline and about the same amount of carbon monoxide, menthanol, and aldehyde emissions. Because methanol does not produce compounds that poison catalytic converters, an automobile burning methanol and equipped with a catalytic converter would produce extremely low levels of any pollutant. In addition, unburned methanol is less photochemically reactive than unburned gasoline and would tend to produce less photochemical smog.

Because methanol has a high octane rating, engines can be set to operate at higher compression ratios and leaner air/fuel ratios. These modifications serve to further reduce the carbon monoxide emissions. Emissions of unburned methanol and aldehyde would, however, tend to increase under these operating conditions.

Methanol/gasoline blend emissions are highly dependent on the engine air/fuel ratio. Because methanol serves to increase the relative amount of air in the air/fuel mixture, engines that have not been adjusted to compensate for this effect often exhibit a reduction in carbon monoxide, hydrocarbons, and nitrogen oxide emissions. However, in engines for which the natural leaning effect (i.e., it increases air in the air/fuel ration) of methanol has been compensated, carbon monoxide and hydrocarbon emissions remain the same while evaporative methanol and aldehyde emissions increase. Although aldehyde emissions have been known to increase by up to 75 percent when methanol blends are used, three-way oxidation catalysts are effective in sharply reducing the aldehyde levels.

Health Concerns

Methanol is a toxic substance that affects the central nervous system, producing headaches, nausea, giddiness, and loss of consciousness. Exposure to methanol by ingestion, inhalation, or dermal absorption may, in severe cases, cause optic-nerve damage and blindness. The toxic effects are believed to result from the formation of metabolic oxidation products, such as formaldehyde or formic acid. The threshold limit value for occupational exposure to methanol is 200 ppm (260 mg/m^3) in air for an 8-hour workday, with a ceiling of 250 ppm (310 mg/m^3) for 15 minutes. More research is needed to characterize the long-term effects of chronic methanol inhalation.

U.S. Department of Energy, Energy Technologies and the Environment: Environmental Information Handbook, Report DOE/EV/74010-1 (Department of Energy, Washington, D.C., December 1980, pp. 14-16 and 14-17.

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tune. Some substantial portion of them may be sufficiently out of tune to discharge large amounts of uncombusted material.

Technoeconomy

It will be hard to imagine a fuel which moves from insignificance to 10 to 20% of the energy basis of the country not having substantial effects on the technoeconomy. (Exhibit 8-13) The most obvious effect intended by national policy would be greater national security and independence from the vagaries of dependency on foreign oil imports. Biomass would also improve balance of payments.

By reducing debt internally, at the local, state, and regional levels, there would be more diverse supply and more local independence and resiliency to disruption. Rural development would probably be stimulated through new jobs and new industry as well as the diversity of employment that would come with rural expansion. To get some sense of impacts on road development we can compare American and Canadian estimates. In 1978 the late David Salo estimated that a 50 megawatt plant would create 771 temporary construction jobs over two to three years, and 282 permanent jobs of which 147 would be in the wood-fired plant plus its wood suppliers. These data come from the New England Energy Congress of 1979. A Department of Energy study estimated 132,000 to 264,000 jobs would result from the industrial and utility long-term growth of wood fuels. This would be accompanied by investments of $24 to $48 billion and annual operating costs of $7 billion (25).

It is interesting to compare completely independently generated data on the impacts of a pulp mill of 600 employees supported by 600 loggers. (Exhibit 8-14)

There are likely to be new competitions for land and water resources.

Poaching has already been mentioned. There are likely to be some shifts in land use from semi and complete wilderness application.

Should public policy not carefully deal with the problem of prompting wood and putting it in fair competition with oil, coal, and natural gas, the matter might be overdone and disrupt the traditional internal and marketing economics of forest products industry.

Among the other potential technoeconomic effects are new industries, chemicals based on wood, new exports such as wood, wood pellets for fuel as well as the exports of knowledge and skill equipment. Finally, there is the stimulation of genetics research and its applications.

On the matter of regional independence, studies in the state of Michigan suggest that by the year 2000 15% of energy supplies could result from wood (26). Work at Georgia Tech suggests an even higher rate in the South (27).

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EXHIBIT 8-13: POTENTIAL ENVIRONMENTAL IMPACTS OF WOOD ENERGY DEVELOPMENT

TECHNOECONOMY

- Competition with other uses of land and water resources
- Rural development, job, industry, diversity
- Shift in land use from semi and complete wilderness
- Crime -- poaching
- Improved balance of payments (less oil imported)
- More local and state energy independence from local and diverse supplies
- Greater national security
- Disruption of forest products industry
- New industries, e.g. chemicals
- New exports -- wool pellets, knowledge
- Stimulate genetics research and application

EXHIBIT 8-14: THE IMPACT OF FOREST OPERATIONS

The pulp mill of 600 employees supported by 600 loggers will create for a community:

Population	3,590
Households	1,000
School children	910
Personal income	$7,100,000
Bank deposits	$2,290,000
Additional employment	650
Passenger cars	970
Retail establishments	30
Retail sales	$3,310,000

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[*] Figures calculated by the U.S. Chamber of Commerce as noted in A Forest Policy for Ontario, a report of the Ontario Economic Council, p. 7.

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Uncertain Effects

While most of the implications discussed above are, to some extent, contingent, conjectural, or uncertain, they all carry a degree of plausibility tied to expanded use. There are other effects that are perhaps less clear. Wood technologies can be operated at a variety of scales as with gasifiers and anaerobic digesters as well as with direct combustion to make wood more accessible to all citizens. The difficult regulatory problems of controlling pollutants from fireplaces, stoves, and furnaces suggest a growth of regulation at the local level, perhaps with requests for a greater Federal, State, Local cooperation coming from the local level. There will be new stakeholder conflicts, as discussed earlier in this report. Esthetics will undoubtedly be affected. The visual effects will be reflected in terms of the degree to which forests are managed. There will be modified recreational opportunities. Some degree of management will increase the recreation potential, some will reduce it. There will certainly be a stimulation in innovation and invention to meet the new technological demands in everything from planting, harvesting, and the applicants of adjutants to the fuel conversion and use end.

Two small industries may flourish and grow to significant size -- wood fuel delivery and good stove and furnace installation and maintenance.

New institutions may develop -- such as silviculture-harvesting cooperatives.

Schools of forestry should boom.

Impacts of Use of Wood in a Central Power Station

The Westbrook Power Station has already been described. (Exhibit 8-5) Since the most likely short-term use of biomass for central power generation will depend upon forest residues, unmerchantable wood, and other materials not normally harvested from forests, the Westbrook Maine facility is a useful example of one set of impacts of one important fuel cycle. In general, the effects are unexceptional, well within the framework of conventional local planning, and present no unique or special new environmental stresses or threats to which EPA should be alert. The Dartmouth group has concluded, consonant with the general conclusions of this study, that the principal environmental consequences will be in collection and harvesting. Let us turn now to some detail in terms of effects during the construction, buildup, and operating phase. While those effects may all be important in the local environment and cause a great deal of local controversy, there is nothing exceptional to them -- just the things that one would associate with any substantial construction operation.

The S. D. Warren Company is a big operation. It produces 172,000 tons of paper a year, employs 2,176 persons, and has a gross payroll of $32 million. The analysis indicates that its new wood-fired steam electric plant will not alter the pulp and paper production nor significantly change employment at the mill. It will lead to retiring of some old boilers and by feeding into the electric grid result in a net estimated saving of $765,900 barrels of fuel oil per year.

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Extracting from the Dartmouth group's study, they also found the following effects:

Construction--

The most significant environmental impacts would result from traffic congestion and noise.

Operation--

The most significant environmental impacts from operation of the proposed wood-fired power plant will result from air pollutant emissions and solid waste disposal. Nitrogen oxide emissions may increase by 660 to 1,030 tons per year. Carbon monoxide emissions may increase by 180 to 450 tons per year. Under worst case conditions, one-hour ground level ambient concentrations of nitrogen oxides may increase by up to 70 micrograms per cubic meter at a distance of 0.8 kilometers from the plant. Similarly, one-hour concentration of carbon monoxide may increase by 10 to 20 micrograms per cubic meter 0.8 kilometers from the plant.

The proposed wood-fired power plant will produce approximately 80 tons of ash per day. This ash will contain small concentrations of toxic metals. Properly landfilled, these substances should pose no hazard to drinking water or aquatic environments.

Harvesting--

The environmental impacts of harvesting are highly management dependent. Properly conducted, harvesting should have few impacts. Many harvest operations do significantly affect the forest environment, however. Soil compaction, erosion, and changes in organic matter content can occur as a result of harvesting. Soil compaction is normally a temporary phenomenon. The most severe erosion incidents typically occur as a result of inadequate use of erosion control mechanisms in the design of forest roads. Erosion results in the loss of critical topsoil, causes gullying, and may reduce the long-term productivity of the forest.

Soil erosion almost inevitably increases sediment loads in streams or ponds. Other harvest impacts on water quality occur as a result of increased nutrient leaching and the removal of trees which shade streams. Both increased nutrient leaching and water temperature may accelerate rates of eutrophication of harvest region water.

Harvest activity may affect the nutrient cycles of forest ecosystems in a variety of ways; systems whose effects are only partially understood. The nutrient impacts of intensive harvesting systems (such as clearcutting) with whole-tree removal may be severe if short harvest rotations are employed. The impacts of less intensive harvest systems would be less severe, although the exact nature of harvest impacts on nutrient cycles is not well understood.

Harvesting may adversely affect wildlife populations if critical stands, such as those providing winter deer yards, are moved. Similarly, some species of birds, such as woodpeckers, are dependent on rotten trees for food and habitats. Failure to leave some such trees would be detrimental to these populations.

Finally, harvesting may affect other uses of the forest such as recreation, and the harvest of trees to produce materials such as pulp or reconstituted boards.

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Transportation--

Some increase in traffic noise levels will occur, however, as will relatively small increases in the emission of air pollutants.

Shutdown--

No attention was given to the ultimate shutdown of the facility.

Some Environmental Benefits Merit Note

A small but significant boost to the Greater Portland area regional economy from construction will occur.

The replacement of the current boiler system will reduce air emissions of total suspended particulates and sulfur dioxide. Emissions of particulates will be reduced by between 240 and 380 tons per year. Emissions of sulfur dioxide will be reduced by between 4,840 and 7.120 tons per year.

Harvesting

Harvesting will create approximately 115 direct jobs and stimulate about 135 indirect positions. Direct annual regional income resulting from the project will total approximately $3.5 million while indirect income will be about $4.3 million. This income will be dispersed throughout the rural portions of the region and will not create a boom town.

Because the proposed wood-fired power plant can burn wood of any quality, it will create silvicultural opportunities for the improvement of the forest. If sound harvest systems are employed and operations are well-managed, both the economic value of the residual stand and its esthetic value could be improved. In addition, harvesting can improve the vigor of aging or overcrowded stands.

When harvesting is applied in a dispersed fashion and creates a patchwork of different habitat types, the diversity and number of wildlife generally increase.

Use of Residues

Currently, many millwood residues from the wood products industry are disposed of in landfills or incinerated in open bark burners. The proposed project will provide an alternative for the disposal of these residues. Combustion of the residues in the proposed wood-fired power plant will reduce the need for landfill space and substantially reduce the emission of particulate matter into the air.

There Are Also Some Potential Longer Term Effects

The operation of the proposed plant will impede the entry or expansion of other wood-using facilities relying on the fuelwood harvest region for the production of low-quality wood. To the extent that potential manufacturing facilities are displaced by the proposed project, the ability of the wood resource to support the employment of the region may be reduced. Materials production requires a much greater labor force per ton of wood consumed than does energy production. On the other hand, the use of wood to produce industrial process steam for the S. D. Warren Mill in Westbrook will help to secure the economic and environmental viability of that facility.

The harvest of about 480,000 green tons of wood per year with whole-tree methods could impact the nutrient cycles and long-term productivity of the harvest forest lands.

Over the expected thirty-year life of the facility, approximately 816,000 tons of wood ash will be generated. The ash from burning wood and oil will contain small quantities of toxic substances including zinc, copper, nickel, chromium, and vanadium. Properly disposed of, these substances do not represent a hazard to water supplies. Should they contaminate surface or ground waters, however, they may accumulate in living organisms within the ecosystem.

The proposed wood-fired steam-electric facility would also contribute directly and materially to three of the four goals of the National Energy Act of October 15, 1976. These objectives are:

o Replacing oil and gas with abundant domestic fuels in industry and electric utilities

o Reducing energy demand through improved efficiency

o Increasing production of conventional sources of domestic energy through more rational pricing policies

o Building a base for the development of solar and renewable energy sources.

RESIDENTIAL AND SMALL-SCALE WOOD COMBUSTION

The risks to human health from air pollution are potentially the most important health and safety risks associated with expanded use of wood for energy. These potential risks are predominantly associated with smoke and particulates from the direct burning of wood in residences and other small facilities.

This subsection first presents some basic facts on residential use (for convenience that term will include small commercial users). Then the reasons why EPA should be concerned with this problem are presented. Of the dozen or so environmental and health and safety problems identified with residential wood burning, a primary and a secondary topic are singled out as central concerns. The rest of the section develops the details.

Under what circumstances and to what extent do POMs (polycyclic organic materials) in smoke present a cancer or other health risk; this is the primary question.

Secondary, but crucial to any policy actions, are the opportunities for

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better design, installation, and maintenance of fireplaces, stoves, and furnaces.

While EPA is already supporting research on wood burning, these two problems are important enough to merit an expanded program.

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Some Incontrovertible Facts

1. Fireplaces, stoves, and furnaces have rapidly increased in sales and use in the last several years.

   In 1970 it is estimated that 800,000 houses used wood as their primary heating fuel. After a decline from 1970 to 1973, use increased some 50% over the next three years. For this six-year period, there was a 15% net increase in residential wood fuel use (28). In North Carolina, manufacturers "report sales of 125,000 airtight wood stoves within the State since the beginning of the present boom in 1976," 50,000 of that figure in 1980 alone (29). The Mitre Corporation has estimated an increase of annual sales from 160,000 in 1972 to over a million in 1978 (30).

2. The use of wood for home heating is on the rise in every place across the country where wood is available.

   The Department of Energy has noted that the "popularity of home wood heating is increasing in several regions of the country." Of the over 900,000 houses heating with wood in 1976, over half were in the South. New England wood energy use has grown sixfold since 1970 (31). Peter Kosel in "Pollution and Fireplaces in California" found that "more wood is burned... in semi-rural northern and mountain counties than in major metropolitan areas" of the state because of "snowfall and proximity to national forests where free firewood is available"(32). Exhibit 6-11, which shows resource concentrations, illustrates this availability-use relationship. It seems likely that pelletization, in combination with higher fossil fuel prices, will make transportation of fuel wood increasingly attractive.

3. As much as 0.85 quads of wood were burned in residential heating in 1979. See Section 3, reference 4.

4. In use, fireplaces, stoves, and furnaces emit smoke and other products. Less smoke is given off by furnaces than by fireplaces or stoves.

   Wood smoke pollution is directly related to inefficient combustion. Design features possible for furnaces - such as precise air-mixture ratios, instrumentation and automatic combustion controls, and catalysts - can greatly improve combustion efficiency of furnaces, ovens, stoves, and fireplaces, reducing associated pollution (33).

5. For a given quantity of wood burned there are more smoky emissions from residential heaters than from large central power stations.

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A central unit will be designed for maximum combustion efficiency and further, will be subject to emissions constraints not applied to residential users.

6. Smoke is rich in POMs - Polycyclic Organic Materials. There are other components to the emissions that are potentially dangerous, such as carbon monoxide, but there is little or no sulphur dioxide.

   "Wood burning appears to emit high concentrations of POMs," most of which is bound to particulates (34). Paul Schwengels of EPA cites two reasons why residential wood burning POM emission may be a potential health hazard -- in the outdoors it is released relatively close to the ground, and indoors there is little dispersion of the material while exposure may take place over many hours (35).

   Sulfur dioxide is considered a minor pollutant. Because it contains little sulfur, wood produces much less of this substance than do the fossil fuels (36).

7. POMs are high in carcinogen and carcinogen-like materials.

   This is a core problem in our discussion of biomass fuel use and will be treated in more depth below.

   "Not all species of POM are proven carcinogens; however many members of this group of aromatic compounds have been shown to cause cancerous or pre-cancerous conditions in test animals, most notably benzo(a)pyrene (BaP)"(37). POM is bound to particulate matter also emitted by wood stoves. The size of these particles influences the exposed tissue and determines concentrations of POM and its transport to and/or from the tissue. Ten of the twelve POMs found in a New Hampshire ambient air assessment are priority pollutants and are referred to as "carcinogenic."(38) John Allen of Battelle notes that these substances "have been found to be carcinogenic."(39)

8. Most emissions are released outside the structure. Closing the damper of a fireplace will show this.

WHY EPA SHOULD CARE

- Residential wood combustion is creating a new air pollution problem.
- There are emissions whose chemical constituents have known effects to human health; and may, in this situation, have a potential for causing cancer.
- These emissions are potentially the most significant human health problem from increased use of wood burning in any form.
- Early and timely action is called for, since the use of residential wood burning is rapidly expanding.
- Technological and regulatory alternatives are unclear.

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- This technology provides an opportunity for innovative interaction with industry, which is eager for more new information and is enthusiastic about the good work of EPA in developing a knowledge base in this area.

- EPA is already involved through its Research Triangle laboratories, and through its joint venture with TVA.

- As a new problem of unknown scope and intensity, it is a good candidate for clarification through research.

- The uncertainty about the risks and the growing public awareness of that uncertainty may have an unncessarily adverse effect on the use of wood, a renewable energy resource.

THE RANK ORDER OF PROBLEMS

As with any new problem involving substantial uncertainty, there are a great number of potential areas to explore. It is a summary judgment of this study that one question is far and away more important than all of the others; and attention to that problem merits, therefore, the most sharp, clear, unequivocal, and immediate focus of research. It is the one question which has the greatest policy implications.

1. Under what circumstances and to what extent do the POMs associated with residential woodburning present a risk of cancer or any other substantial risk to human health?

A second critical question has to do with being prepared to deal with any bad news in response to the first question:

2. What are the opportunities for better design, installation, and maintenance of fireplaces, stoves, and furnaces?

Other questions less critical or derivative of one and two are:

3. Are the risks primarily indoor or outdoor?

4. To what extent will the expanded use of residential woodburning lead to important but derivative localized environmental risks and air pollution problems from the burning of contaminated wood from construction scrap, waste such as crankcase oil, etc., or from the use of coal as backup in facilities not designed for coal?

5. Is carbon monoxide a problem of any practical significance?

6. Is there anything special about the problems of fire resulting from improper installation and other aspects of burning which require special attention?

7. Are accidents associated with harvesting for residential use a problem which should be handled on any basis other than public information

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about the use of chain saws and other technologies?

8. Are matters of burns, scalds, and other accidents associated with having an intrinsically dangerous item in the household, subjects of any special information needs?

9. To what extent is poaching a growing and significant environmental problem as opposed to a simple problem of theft and property rights?

The rest of this section gives the details on the problems outlined. First is a brief description of residential wood heating systems, which shows why a particular fireplace, stove, or furnace may be more or less desirable. The discussion then moves to the scope and trend in use. Problems and risks associated with use follow, with emphasis on emissions from combustion. The subsection concludes with a discussion of research underway, problems with regulation, and our own recommendations.

The Scope of Conversion

There are three ways to directly heat a house with wood: fireplace; stove; and central heating. These were discussed on pages 97-99.

Studies presently agree, with exception, that the use of wood for residential space heating has been increasing for over the last decade. This growth is expected to continue. As discussed earlier, this increased use will be a local and regional phenomenon, at least until it becomes cost-effective to transport chips or pellets to new market areas. The 201-county area of the Tennessee Valley Authority is one region which is encouraging this trend in a systematic way. Vivian Aubuchon of the MITRE Corporation, in a study done for EPA's Integrated Assessment Program, states that an estimated 13.7 percent of homes in the TVA area used wood for more than 90 percent of their heat. This was roughly equivalent to 34 trillion BTU's. Ninety trillion BTU's could be replaced if the user figure reached 40 percent. This shows the magnitude of change possible in a region capable of supplying its own wood needs (40). According to a MITRE Corporation report, "over 50 percent of the large increase in the use of wood for residential heating since 1973 has occurred in southern states" (41). In New England, as noted earlier, the use of wood for residential heating has increased enormously. It is reasonable to assume continued increase in the price of fossil fuels, and a parallel rise in the use of wood for residential heating since its price will probably track somewhat below that of #2 fuel oil, because of added inconvenience (42).

PROBLEMS AND RISKS

There are several environmental problems and health hazards associated with increased residential use of wood fuel. Among these are:

- harvesting-related problems; including: damage to the forest ecology, accidents, and poaching;

- injuries related to fireplace, stove or furnace use (burns, fire, etc.);

- indoor and outdoor air pollution from combustion;
- problems associated with the use of inappropriate combustibles.

Harvesting of timber for residential heating does not generate problems different from those already discussed in industrial harvesting, but increased small scale harvesting needs to be considered. There are data to indicate that individuals gathering wood for their own heating or local sale have had detrimental impacts. Few homeowners or new lumberjacks are trained in forest management: the result may be the loss of valuable saw timber to firewood and removal of readily accessible growth while lesser-value trees remain standing. Related to this is the problem of private landowners. There is nothing to stop members of this group from taking a short-term gain to the long-term detriment of an area's forests. Martin Jones of MITRE notes that "once timber production has been harvested, usually little of it is replanted by private owners, which greatly reduces its potential for timber production" (42). Admittedly this is an extreme, but any widespread ill-managed harvesting will have negative impacts on the future use of a timberstand. As firewood prices rise, temptation for the private holder to allow indiscriminate harvesting and neglect of replanting and management will increase.

Working in the woods with chainsaw or axe is dangerous. From 1976 to 1977 25.1 - 26.3 workers per hundred fell prey to injury or illness related to wood harvesting. This was nearly three times the rate for all private industry (43). These were professionals, and though there are no figures available for novices, the ratio is presumably higher. Increased numbers of inexperienced chainsaw operators in the woods will mean more injuries.

People steal firewood. Until now poaching has usually been associated with valuable lumber, such as black walnut, rather than firewood. As prices rise this may change, but firewood poaching may be less an environmental problem and more a criminal one. The older seed trees have more environmental importance than do the younger trees a firewood poacher is likely to want.

Fire Use

A highly visible risk from residential wood heating is that of fire and accompanying injuries. As more wood heaters are used we can expect incidents of fire to rise. The causes of these fires and/or injuries apparently often lie with the user and not the devices. A National Bureau of Standards study, as reported by DOE, showed that in one series of fires 75 percent were caused by unsafe installation and 25 percent by faulty operation and maintenance (Exhibit 8-15). Faulty design or defects were related in only 2 percent of the cases. In another NBS study most of the 11,534 fires reported were caused by improper installation or use. One area of concern is chimney fire, which was responsible for 35 percent of the fires in the study mentioned above. As wood burns its smoke deposits a tar-like substance, called creosote, on the walls of the chimney or flue. Creosote burns fiercely once ignited. Proper installation and maintenance, such as sweeping the chimney, can prevent many fires. Burns and scalds associated with wood heating equipment are associated with sparks or the hot stove surface. Poplar logs when burning, for example, are noted for periodical spitting smouldering embers. On the

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other hand, experience tells us that technological changes can reduce the risks of accidents.

Thomas Patterson of the University of Vermont's Extension Service has reviewed the statistics on house fires caused by wood stoves. The data are shaky, because statistics are not systematically collected and the diagnosis of causes is often done by untrained people. Nevertheless, the data strongly suggest that wood burning stoves may be one of the leading causes of home fires where domestic wood burning is commonplace. For example, in Idaho some 24 percent of all home fires were attributed to wood burning stoves. For Montana and Oregon, the best estimates are 20 percent and 30 percent respectively (44).

EXHIBIT 8-15: CONDITIONS LEADING TO FIRES ATTRIBUTED TO WOODBURNING EQUIPMENT

Condition	Number of Fires	Percent
Ignition of Combustibles	1,895	18
Exterior Fire from Sparks	963	9
Chimney Fires	623	6
Improper Fueling Technique	578	5
Equipment Malfunction	457	4
Use of Flammable Liquids	126	1
Other	28	2 (sic)
Improper Maintenance	2,875	27
Improper Equipment Design	1,050	10
Improper Operation	787	8
Ignition of Structure	702	7
Improper Installation	248	2
Improper Chimney	138	1
	10,470	100

Source: U.S. Department of Energy, Health Effects of Residential Wood Combustion, Report DOE/EV-0114, September 1980: 18.

Emissions

Burning wood produces many by-products, especially if the fires are smoky (Exhibit 8-16). Wood produces dirty emissions, especially more carbon monoxide, particulate matter, and polycyclic organic matter (POM). (See Exhibit 8-17).

The details of wood as a dirty fuel compared to gas and oil are conveniently illustrated in Exhibit 8-18, prepared by John Cooper, based on his own work and that of the Monsanto Group and earlier studies by the National Academy of Sciences. The data shows that wood burning is polluting even relative to vehicle emissions and to central power stations operating on coal.

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EXHIBIT 8-16: WOOD SMOKE COMPONENTS

Particulates

Particulates is a catch-all term which includes inorganic ash, condensable organics, and fine carbon char. About 50-75% of particulates are of respirable size. The rate of emission of different sizes and species of particulatesis highly variable depending on wood moisture content, the species of wood burned, the stove or furnace design, and the speed and completeness of combustion. Particulates are the most visible pollutant from wood burning and the greatest health hazard. They include POMs (see below). Wood burning is a dirty process; the amount of particulates released is an order of magnitude higher than from oil furnaces.

Carbon Monoxide

Low temperature, inefficient combustion in wood stoves produces high levels of carbon monoxide. Every winter, deaths are recorded from carbon monoxide poisoning in poorly ventilated homes and apartments heated with wood.

Hydrocarbons

Under very poor combustion conditions, volatile hydrocarbons may be released. The energy of sunlight converts these into peroxy compounds -- strong oxidizing agents which in turn can oxidize nitric oxide to nitrogen dioxide. This cycle displaces the normal pathway for the reduction of ozone. The net result is localized increases in the ozone concentration which produces photochemical smog.

POM (Polycyclic organic matter)

POMs emitted from wood burning include such identified carcinogenic villains as benzo(a)pyrene, benzofluoranthene and acenaphthylene. Emissions of benzo(a)pyrene are estimated to be fifty times greater than from oil combustion. Synergistic effects are also possible.

Radioactivity

All emissions studies have been negative, although some indicate trace amounts in the ash.

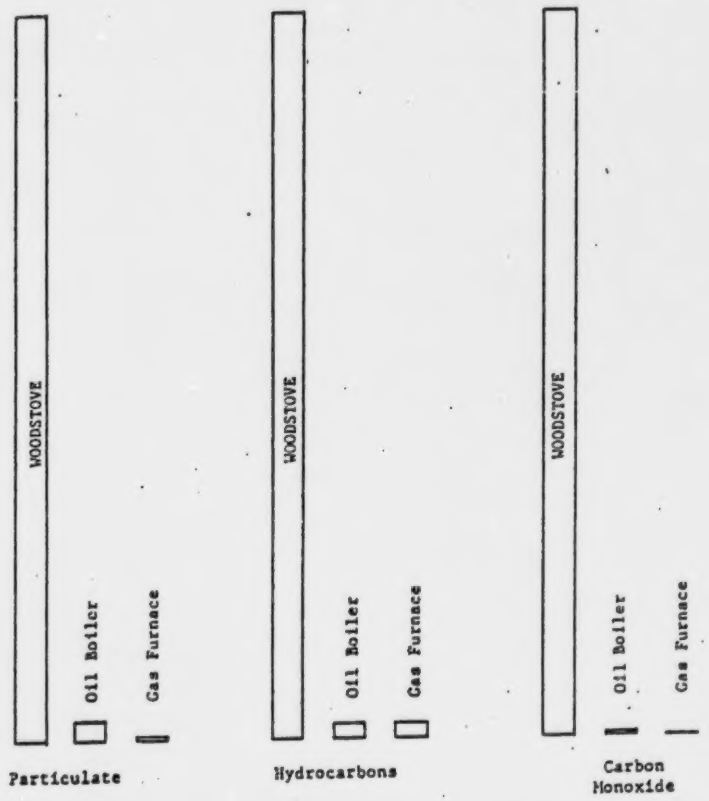
Nitrogen Oxides

Wood burning stoves produce small amounts of nitrogen oxides, less than open fireplaces, a benefit of the lower temperatures of combustion.

Sulfur

Sulfur dioxide emissions are negligible, especially in comparison with fossil fuels.

EXHIBIT 8-17: EMISSIONS FROM RESIDENTIAL HEATERS PER UNIT OF HEAT DELIVERED TO THE DWELLING: Efficiencies of 50% (woodstove) and 75% (gas furnace and boiler) were assumed. Emission values were normalized with respect to woodstove emissions.



*Source: D.R. Jaasma, Measurements of Chemical Changes due to Catalysts of Wood-stove Effluent. Presented at the Wood Heating Seminar, New Orleans, February, 1981.

Cooper's table also points up that the stove is relatively more polluting than the fireplace with regard to carbon monoxide and BaP (benzo(a)pyrene) production. Emissions from wood heaters are related to combustion efficiency. The desire to burn the least amount of wood to produce the most heat may lead the owner to damp the fire down to a low temperature, which lowers combustion efficiency and increases emissions. Incomplete combustion and lack of secondary combustion causes especially high levels of particulates, carbon monoxide, and organics. A fireplace, which consumes four times as much wood as a stove to produce the same amount of heat, reaches higher combustion temperatures and produces less emissions. Exhibit 8-19 from the EPA/Monsanto study reported that carbon monoxide and POM emissions rates were an order of magnitude lower for the fireplace than for the stove.

EXHIBIT 8-18: COMPARISON OF EMISSIONS FROM SELECTED RESIDENTIAL SPACE HEATING, POWER GENERATION, AND TRANSPORTATION SOURCES

Source	CO lb/10^6 Btu	NO_x (as NO_2) lb/10^6 Btu	SO_x (as SO_2) lb/10^6 Btu	B(a)P μg/10^6 Btu	Particulates lb/10^6 Btu
Residential Space Heating					
Gas	0.02	0.08	0.0006	80	0.02
Oil	0.04	0.09	0.3 - 7	900	0.07
Coal	3.5	0.1	0.5 - 7	2,500,000	0.6
Wood: Firplace	3.0	0.25		45,000	1.3
Wood: Stove	22	0.07	0.03	135,000	1.2
Power Generation					
Coal				(20 - 400)	
Transportation (lb/50 mi)	lb/50 mi	lb/50 mi	lb/50 mi	μg/50 mi	lb/50 mi
Highway vehicles	2.4	0.34	0.02	50	0.06

*Source: Cooper, John A. (1980), "Environmental Impact of Residential Wood Combustion Emissions and Its Implications," Journal of Science Pollution Control Association, Vol. 30, No.8.

EXHIBIT 8-19: SUMMARY OF EMISSION RESULTS FOR CRITERIA POLLUTANTS AND POM's FROM WOOD-FIRED RESIDENTIAL COMBUSTION EQUIPMENT

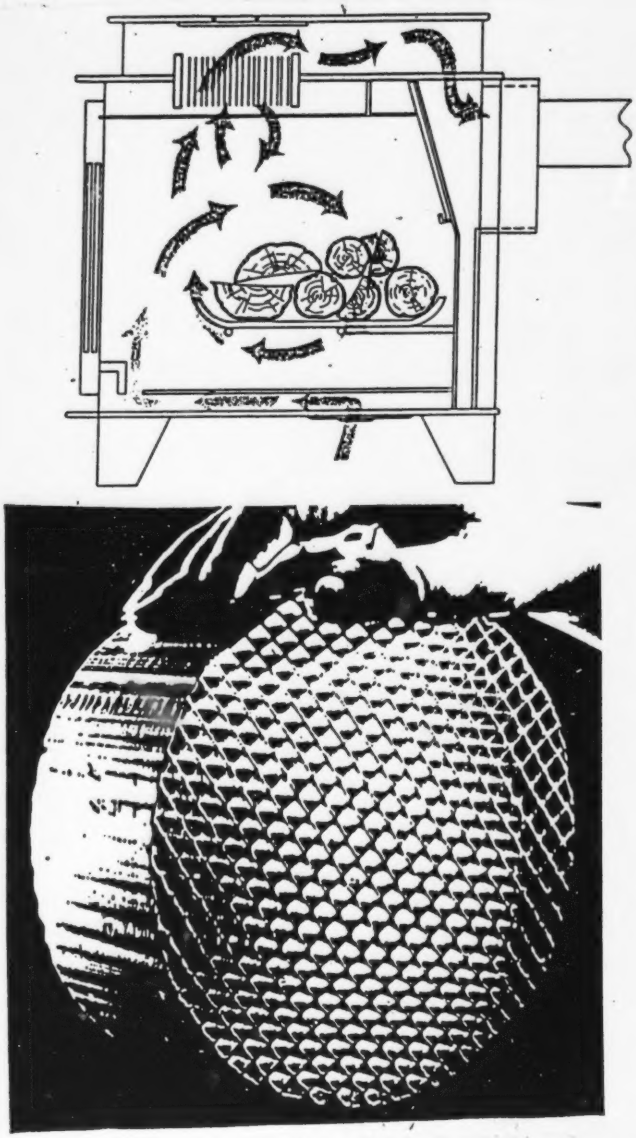
Wood burning device	Wood type	Emission rate, g/kg[a] (μg/J)[b] Particulate matter	Condensable organics	Volatile hydrocarbons	NO_x	SO_x	CO	POM
Fireplace	Seasoned oak	2.3 (0.13)	6.3 (0.35)	19 (1.1)	2.4 (0.13)		30 (1.7)	0.025 (0.0014)
Fireplace	Green oak	2.5 (0.19)	5.4 (0.40)		1.9 (0.14)		22 (1.6)	
Fireplace	Seasoned pine	1.8 (0.10)	5.9 (0.32)		1.4 (0.08)		21 (1.2)	
Fireplace	Green pine	2.9 (0.21)	9.1 (0.67)		1.7 (0.13)		15 (1.1)	0.036 (0.0026)
Baffled stove	Seasoned oak	3.0 (0.17)	4.0 (0.22)		0.4 (0.02)		110 (6.2)	0.21 (0.012)
Baffled stove	Green oak	2.5 (0.19)	3.8 (0.28)		0.7 (0.05)		120 (9.0)	
Baffled stove	Seasoned pine	3.9 (0.21)	4.1 (0.23)	2.8 (0.15)	0.5 (0.03)		270 (15)	0.37 (0.020)
Baffled stove	Green pine	7.0 (0.51)	12 (0.88)		0.8 (0.06)		220 (16)	
Nonbaffled stove	Seasoned oak	2.5 (0.14)	6.0 (0.34)		0.4 (0.02)	0.16 (0.009)	370 (21)	0.19 (0.011)
Nonbaffled stove	Green oak	1.8 (0.13)	3.3 (0.25)	0.3 (0.02)	0.5 (0.04)		91 (6.8)	
Nonbaffled stove	Seasoned pine	2.0 (0.11)	5.6 (0.31)		0.2 (0.01)	0.24 (0.013)	150 (8.2)	
Nonbaffled stove	Green pine	6.3 (0.46)	10 (0.74)	3.0 (0.22)	0.4 (0.03)		97 (7.1)	0.32 (0.024)

a-grams of pollutant emitted per kg of wood (as-received basis) burned.
b-blanks indicate no data were obtained.

*Source: D.G. DeAngelis, D.S. Ruffin, and R.B. Reznik, "Preliminary Characterization of Emissions from Wood-Fired Residential Combustion Equipment," EPA-600/7-80-040 (March 1980).

Design changes can reduce stove emissions. One of these is a catalytic combustor developed by Corning Glass Works. The device is similar in concept to the catalytic converter in automobile exhaust systems. The device is a ceramic honeycomb impregnated with noble metals (i.e., gold, iridium, platinum, palladium, mercury, silver) which oxidizes volatilized hydrocarbons and carbon monoxide to cut down on total emissions and creosote buildup while greatly increasing the overall efficiency. Corning Glass claims a 20% decrease in wood use and a 90% efficiency for the stove -- up 30-35% over existing airtights (Exhibit 8-20). It is not clear which organics are

EXHIBIT 8-20: CORNING STOVE DESIGN WITH CATALYTIC COMBUSTOR



Source: R.D. Van Dewoestine et al. Catalytic Combustion in Residential Woodstoves. Presented at Wood Heating Seminar. New Orleans, February, 1981. Wood Heating Alliance 1981, pp. 154-66.

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preferentially burned and it is not clear that consumers are ready to invest in the device when it is marketed. Less exotic design changes have altered emissions as well, primarily through secondary combustion. Levels, however, remain high compared to the fossil fuels. There are a number of technical approaches to the control of emissions from residential wood burning. Many of these, based on the experimental work of Allen and Cooke of Battelle Columbus Laboratories for EPA, are summarized in Exhibit 8-21. It is worth noting that the majority of the modifications require change in design but many of them are applicable to existing stoves.

Of the numerous hazardous products of wood combustion one group stands out as central and as needing immediate attention -- the polycyclic organic matter (POM). Many compounds fall under this heading, and while not all are recognized as carcinogenic, many are; most notably benzo(a)pyrene. It is not clear which POMs, in which combinations, and under what circumstances, are harmful to humans. Open questions are abundant. What wood types emit certain POM? What are the results of combustion of combinations of wood types? Will wood types have an effect on the bonding of POM to particulates? How do these compounds interact with the indoor, or the outdoor, atmosphere? We know little which would answer these and other questions about POM, but work should begin immediately to broaden our knowledge and reduce uncertainty which might interfere with achieving the benefits associated with increased residential wood heating.

There are related potential health risks from residential wood combustion caused by other classes of compounds. Agents which affect the cilia and mucus are found in smoke (Exhibit 8-22a) as are cancer promoting agents (Exhibit 8-22b). Any research directed at pursuing the POM problems should also, of course, include these agents as well.

Polycyclic Organic Matter (POM)

Several studies have been conducted in the last few years dealing with polycyclic organic matter (POM) or what are sometimes called polycyclic aromatic hydrocarbons (PAH) associated with the combustion of wood in fireplaces, stoves, and other small scale burners. While they belong to a class of chemicals, many of which are known carcinogens, there is not concrete evidence directly relating the POM's or PHS's to human health effects. A critical need at this point is to determine whether there are health effects.

Detailed understanding of the relationship between conditions of combustion and the production of these potentially dangerous materials is somewhat confused because the laboratory efforts to reproduce or simulate realistic domestic burning practices in the laboratory run into a number of problems. The second difficulty common in most new fields of research is that the experimental and the analytical procedures are not fully standardized or reproducible from laboratory to laboratory. Consequently, while one can draw useful and experimentally sound conclusions from a series of experiments run in any particular laboratory, the comparison of data from one laboratory to another is not so clear or useful. For example, POM production from different laboratories under roughly similar conditions of combustion are reported to vary by as much as a factor of 10. What is undeniable is that POMs are

EXHIBIT 8-21: SUMMARY OF EMISSIONS CONTROL TECHNIQUES

Factors Adversely Affecting Emissions	Approaches for Possible Improvements	Principal Modifications Required	Applicable to existing Stoves
Premature Pyrolysis in Wood Magazine Within Stove	1. Prevent heating of wood inventory	Design	No
	2. Feed wood in frequent small amounts	Operation	Yes
	3. Use large wood pieces, low surface to volume ratio	Fuel	Yes
	4. Burn moderate moisture content wood to retard pyrolysis	Fuel	Yes
	5. Burn devolatilized wood, charcoal	Fuel	Yes
Pyrolysis Rate in Primary Combustion Area Exceeds Local Air Supply Preventing Complete Combustion	1. Maintain high rate of primary air supply, with ensuing high burning rates	Operation	Yes
	2. Focus air supply into limited burning area to prevent widespread burning	Design	Retrofit
	3. Maintain high turbulence in active combustion region	Design	No
	4. Limit quantity of fuel in active burning area, i.e. approach fuel-controlled burning	Design	No
	5. Maintain high temperatures in active burning area	Design	Retrofit
	6. Avoid sharp and/or frequent reductions in air supply rate	Operation	Yes
Control of Emissions in Primary Burning Area	1. Provide high level of turbulence in burning area to promote mixing	Design	No
	2. Maintain high temperatures in burning area	Design	Retrofit
	3. Provide long gas residence time at the high temperatures	Design	No
	4. Duct pyrolysis products from magazine into burning area	Design	No
	5. Provide down draft combustion, with bed area reduction to accommodate low burning rates	Design	No
Control of Emissions in Secondary Combustion Zone	1. Maintain high temperatures	Design	Retrofit
	2. Use heated secondary air	Design	No
	3. Increase combustible content of primary combustion products	Design	No
	4. Provide auxiliary combustion using an ignition source and/or supplementary fuel	Design (Operation)	No
Add-on Systems Affecting Emissions Reduction	1. Use catalytic afterburner	Design	Yes
	2. Use separately fueled afterburner	Design	Yes
	3. Add heat storage capacity to the system, permitting other modifications to be acceptable for consumer utilization.	Design	Yes

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Source: John M. Allen. "Control of Emissions from Residential Wood Burning by Combustion Modification." Proceedings Documents for Wood Heating Seminars 1980/1981. Washington, D.C.: Wood Heating Alliance, 1981. pp. 189, 190.

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EXHIBIT 8-22a: EMISSION FACTORS FOR CILIA TOXIC AND MUCUS COAGULATING AGENTS OBSERVED IN SMOKE AND FLUE GAS FROM RESIDENTIAL WOOD COMBUSTION SOURCES

Compound	Stoves	Fireplaces
Formaldehyde	0.2	0.4
Propionaldehyde	0.2	---
Acetaldehyde	0.1	---
Isobutyraldehyde	0.3	0.5
Phenol	0.1	0.02
Cresols	0.2	.06

(grams emissions per kilogram wood)

6-1/2"

EXHIBIT 8-22b: INITIATING OR CANCER-PROMOTING AND CO-CARCINOGENIC COMPOUNDS IN SMOKE FROM RESIDENTIAL WOOD COMBUSTION SOURCES

9-1/8"

Compound	Emission Factors (g/Kg)	
	Stoves	Fireplaces
Catechol	0.01	.014
Phenols	0.1	0.02
Pyrene	0.019	0.0016
Fluoranthene	0.022	.0016

(grams emissions per kilogram wood)

Source: U.S. Department of Energy, Health Effects of Residential Wood Combustion: Survey of Knowledge and Research. Report DOE/EV-0114 UC-586. Sept. 1980, from J.A. Cooper, "Environmental Impact of Residential Wood Energy Combustion: Emissions and Its Implications," presented at the Wood Energy Institute, Wood Heating Seminar VI, Atlanta, Georgia, February 25-28, 1980, after D.G. DeAngelis et al, "Source Assessment: Residential Wood Combustion," Monsanto Research Corporation (Dayton, Ohio), research in progress for the U.S. Environmental Protection Agency, Research Triangle, North Carolina, and D. Hoffman and E.L. Wynder, Environmental Respiratory Carcinogens," in Chemical Carcinogens, ed. by C.E. Searle, American Chemical Society, p. 339, 1976.

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produced in combustion and that conditions of combustion do strongly influence their rate of production.

The bench mark study by deAngelis, Ruffin, and Reznik of Monsanto for EPA (45 and 46) was a real eye opener for many people who saw biomass as a fundamentally benigh energy source. One EPA program manager is quoted as saying, "When we first started that Monsanto study, I thought it was a complete waste of time, and was I ever wrong...I made some of the most conservative assumptions I could possibly make and what I came up with was that wood emitted more POM than any other fuel, with the possible exception of residential coal combustion." That observation was the red flag that alerted EPA and should alert the rest of the research and policy community to the potential significance of wood emissions (47).

Exhibit 8-23 shows the work of Allen and Cooke at Battelle and compares PAH emissions in the Monsanto report with their own research. That exhibit points up several factors. Although the experimental conditions are roughly comparable between the two laboratories, the total emissions in the three Monsanto cases reported averaged 190 milligrams of PAH emissions per kilogram of wood, whereas the Battelle work averaged 17 milligrams per kilogram. Allen and Cook summarized the similarities and differences: "Both studies found that the lower molecular weight PAH were produced in larger amounts than larger molecules and both studies showed that anthracene and phenathrene are a large fraction of the PAH produced. This finding suggests that benzene may be produced in significant amounts during residential wood combustion and future studies of wood combustion product should include this important suspect carcinogen and its measurements."

"The apparent differences in levels of PAH measured in the two studies can possibly be explained by differences in stove operating parameters or possibly by the difference between the packed column gas chronatographic technique used in the earlier report compared to the glass capillary method used in this study...Since these two studies were not conducted identically, the observed differences in PAH emissions are well within the variability of this type of emission measurement, and the variability in operating parameters for the stoves tested" (48). Even more striking differences, dependent on experimental conditions, are revealed in the work of Hubble et al at Argonne National Laboratory. Their work summarized and compared with the experiments at Monsanto and Battelle (Exhibit 8-24). There is again a striking difference in report POM production and substantial variation in the production of other emissions. The work of Hubble and his associates comes to a number of interesting conclusions, perhaps the most important of which is that "Future work should focus on quantification of the chemical characterization of stove emissions before assessment of impacts on health and environment" (49). They found eventually that high burn rates compared to lower burn rates produce a simpler mixture of compounds and a shift to multiring aromatics and thus to higher POM emission rates. They also found, however, that the total organic emissions, particularly creosotes and condensable organics decreased as the burn rate or firebox or stack gas temperature increased. Hubble and Harkness (50) found that log size had a pronounced effect on emissions. Smaller logs create greater concentrations of particulates and in creosote. They also found that the highest systems efficiencies

EXHIBIT 8-23: COMPARISON OF REPORTED PAH EMISSIONS (mg/kg or lb/10^6 lb Wood Fuel)

Stove Fuel	Baffled(a) Oak(c)	Non-Baffled(a) Oak(c)	Non-Baffled(a) Pine(d)	Side Draft(b) Oak(e)	Side Draft(b) Pine(d)	Up Draft(b) Oak(e)	Down Draft(b) Oak(e)	High Turbulence(b) Oak(f)
Compound (Class)								
Anthracene/ Phenanthrene	75	62	103	2.0	7.5	2.6	15	2.4
Methylanthracenes/ Methylphenathrenes	39	38	70	1.9	1.2	1.0	9.3	0.9
Pyrene	16	17	19	1.1	0.8	0.7	5.2	0.6
Methylpyrenes/ Methylfluoranthenes	13	10	14	0.1	0.1	0.2	0.4	0.1
Benzo(a)anthracene/ Chrysene	13	7.6	1.3	1.3	0.6	2.3	2.0	0.3
Benzofluoranthenes	13	11	14	1.4	1.8	1.9	0.5	0.1
Benzopyrenes/Perylene	8.3	8.4	9.4	0.9	1.9	1.9	0.1	0.2
Indeno(1,2,3-cd)pyrene	0.07	-	-	1.4	3.2	0.5	0.04	0.1
Benzo(g,h,i)perylene	4.5	4.3	4.8	2.1	2.5	0.5	0.03	0.07
Total	180	160	240	12	20	12	33	4.8

(a) Monsanto Report, EPA-600/7-80/040.
(b) Battelle Columbus Report, EPA-600/71-81-091.
(c) Seasoned.
(d) Green wood, split logs.
(e) Seasoned, triangular sawed pieces.
(f) Seasoned, split logs.

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occurred at the highest pollution concentrations, that is, under low burn rate.

Indoor vs. Outdoor Risks

Another question of concern is the relative concentration of wood emissions indoors and outdoors, and the aggregate impact on certain communities and region of outside wood burning.

Most wood smoke is vented to the outdoors -- this is obvious. There are emissions within the house as well, and this is potentially hazardous because of the duration of exposure. On a severe winter day a person may remain indoors for 14-24 hours. The effects of this length exposure to the materials emitted into the indoor environment, POM's and carbon monoxide at the least, need to be investigated.

GEOMET Technologies, Inc. recently conducted a study entitled "Residential Indoor Air Quality and Wood Combustion". The authors found that "....wood-burning appears to be a major source of particulate matter emissions within the residential environment. Consequently, wood burning may lead to elevated indoor concentrations of TSP (total suspended particulates), RSP (respirable suspended particulates), and BaP (benzo(a)pyrene) that would be a significant factor in human exposure" (51).

EXHIBIT 8-24: SUMMARY OF PUBLISHED RANGES OF EMISSION FACTORS WITH CORRESPONDING EXPERIMENTAL CONDITIONS

Study	Wood Type[a]	Wood Shape and Size,[b] m	Burn Rate, kg/hr	Sample Probe Temperature, °C	Firebox Temperature, °C	Emission Factor, g/kg CO	Emission Factor, g/kg Particulate
ANL[1]	sro	0.12ϕ, Ł	0.82-2.58	55-175	250-360	138-196	0.8-22.2
ANL[1]	sro	0.06ϕ, Ł	3.9 -7.7	200-400	500-≥800	92-148	0.5- 2.3
Monsanto[2,3,4]	so, go, sp, gp	0.08ϕ, Ł	6.0 -8.4	40-250	N.D.[c]	15-370	0.6- 6.3
Battelle[5,6]	o[d], gp, fb	0.10x0.10x0.14Δ, Ł, 0.03ϕk	2.9-13.6		N.D.	33-400	N.D.

Study	Volatile Organic	Condensible Organic	Total Hydrocarbon	NO_x	POM	Creosote
	Emission Factor, g/kg					
ANL[1]	N.D.[c]	3.0-8.4[e]	N.D.	N.D.	0.004-0.040	0.28-2.51
ANL[1]	N.D.	0.8-2.1[e]	N.D.	N.D.	0.008-0.030	0.10-0.38
Monsanto[2,3,4]	0.3-19.0	2.2-12.0	N.D.	0.2-2.4	0.025-0.37	N.D.
Battelle[5,6]	N.D.	N.D.	2-113	0.5-5.0	0.011-0.0050	N.D.

[a] sro-seasoned red oak; so-seasoned oak; sp-seasoned pine; ssm-seasoned sugar maple; gp-green pine; fb-fir brands; o-oak; p-pine; go-green; wp-white pine; b-birch; ro-red oak (0-65% moisture).
[b] ϕ-diameter, Ł-split log, L-log, Δ-triangular-shaped oak lumber, k-kindling. [c] Not Determined.
[d] -cured, air dried. [e] See ref. 7.

Sources:

1. B.R. Hubble and J.B.L. Harkness, "Results of Laboratory Tests on Wood-Stove Emissions and Efficiency," Proceedings of the EPA Conference on Wood Combustion Environmental Assessment, February 21-24, 1981, New Orleans, La.

2. D.G. DeAngelis, D.S. Ruffin, and R.B. Reznik, "Preliminary Characterization of Emissions from Wood-Fired Residential Combustion Equipment," "EPA-600/7-80-040 (March 1980).

3. D.G. DeAngelis, D.S. Ruffin, J.A. Peters, and R.B. Reznik, "Source Assessment: Residential Combustion of Wood," EPA-600/2-80-042b (March 1980).

4. J.A. Peters, T.W. Hughes, and D.G. DeAngelis, "Wood Combustion Emissions at Elevated Altitudes," Proceedings of the EPA Conference on Wood Combustion Environmental Assessment, February 21-24, 1981, New Orleans, La.

5. J.M. Allen, "Control of Emissions from Residential Wood Combustion by Combustion Modification," Proceedings of the Joint Symposium on Stationary-Combustion NO_x Control, Vol. III: NO_x Control and Environmental Assessment of Industrial Process Equipment, Engines, and Small Stationary Sources, IERL-RTP-1085 (October 1980).

6. J.M. Allen, "Control of Emissions from Residential Wood Burning by Combustion Modification," Proceedings of the EPA Conference on Wood Combustion Environmental Assessment, February 21-24, 1981, New Orleans, La.

7. B.R. Hubble, J.R. Stetter, E. Gebert, J.B.L. Harkness, and R.D. Flotard, "Experimental Measurements of Emissions from Residential Wood-Burning Stoves," Proceedings of the 1981 International Conference on Residential Solid Fuels, June 1-4, 1981, Portland, Oregon.

The study was conducted in the suburban Boston metropolitan area. Air quality measurements were made in and around residences with wood stoves and fireplaces.

While the authors are cautious in interpreting their results they do point up the significance of the data in indicating a potential long-term health consequence.

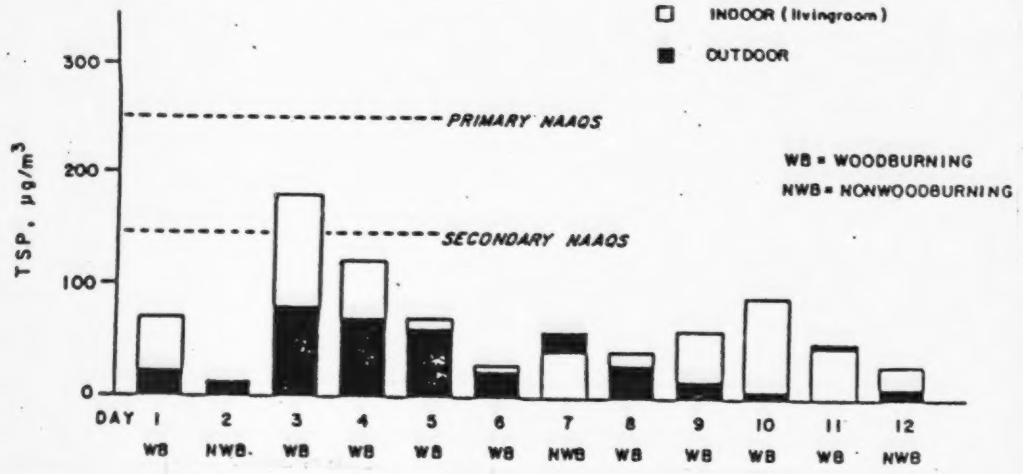
Exhibit 8-25 shows the relation between residential indoor air quality and wood combustion, both indoors and outdoors, in terms of total suspended particulates (TSP). Exhibit 8-26 presents comparable data for respirable suspended particulates (RSP). These are particularly important because, by definition, they are the particles most likely to penetrate the lungs.

Exhibits 8-27/8-28 entabulate average values for total suspended solids and respirable solid particulates found in the Geomet study.

Exhibit 8-29 shows BaP concentrations in relation to wood burning and non-wood burning days. For a rough comparison, Exhibit 8-30 shows the ambient BaP concentration in various locations. BaP is of course a major component of POM.

The concern with toxicants from residential wood combustion is not limited to the United States and at the same conference in which the Geomet results were reported, Nilsson of the National Swedish Environmental Protection Board reported similar data and concerns to those found in the United States and suggested that "the most critical substance in emissions from wood combustion seems to be PAH, benzene, and perhaps ethene (52).

EXHIBIT 8-25: INDOOR AND OUTDOOR 24-HOUR TSP CONCENTRATIONS AT RESIDENCE A



Source: Moschandreas, D.J. et al., (1981) "Residential Indoor Air Quality and Wood Combustion" Presented at the 1980/1981 Wood Heating Seminar sponsored by the Wood Heating Alliance, Feb. 21-24, 1981. New Orleans, La.

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EXHIBIT 8-26: INDOOR AND OUTDOOR 24-HOUR RSP CONCENTRATIONS AT RESIDENCE A

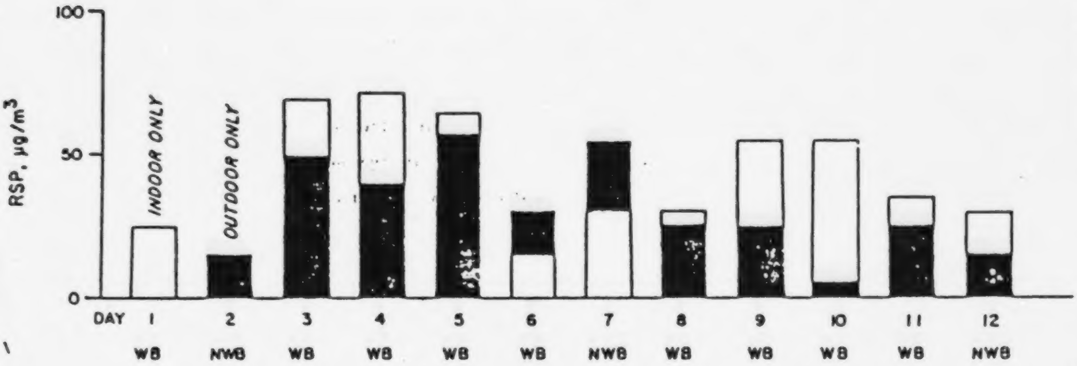

EXHIBIT 8-27: INDOOR-OUTDOOR 24-HOUR TSP CONCENTRATION CHARACTERISTICS OF WOODBURNING AND NONWOODBURNING DAYS

Residence	Location	TSP (µg/m³) Woodburning Average	Woodburning In/Out Ratio	Woodburning Range	Nonwoodburning Average	Nonwoodburning In/Out Ratio	Nonwoodburning Range
Residence A (Stove)	In	85.1	1.8	32.5 - 180.6	28.3	1.0	13.6 - 42.0
	Out	46.5		10.0 - 79.5	28.9		10.7 - 60.2
Residence B (Fireplace)	In	267.0	6.1	Only One Woodburning Day	81.0	2.1	31.2 - 137.5
	Out	44.0			38.1		12.3 - 140.5
Residence C (Fireplace)	In	183.6	8.5	Only One Woodburning Day	52.8	1.5	24.8 - 116.2
	Out	21.6			35.3		17.4 - 57.3

Source: Moschandreas, D.J. et al., "Residential Indoor Air Quality and Wood Combustion" Presented at the 1980/1981 Wood Heating Seminar sponsored by the Wood Heating Alliance, Feb. 21-24, 1981. New Orleans, La.

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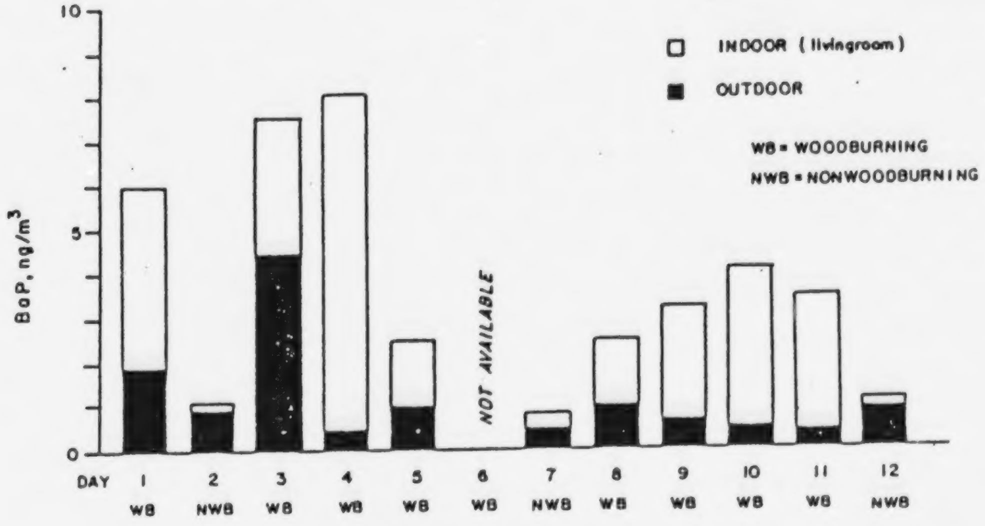
EXHIBIT 8-28: INDOOR-OUTDOOR 24-HOUR CONCENTRATION CHARACTERISTICS OF WOODBURNING AND NONWOODBURNING DAYS

Residence	Location	RSP (µg/m^3)					
		Woodburning			Nonwoodburning		
		Average	In/Out Ratio	Range	Average	In/Out Ratio	Range
Residence A (Stove)	In	49.0	1.4	14.3 - 72.5	28.0	1.0	23.9 - 31.6
	Out	34.2		22.6 - 57.6	27.4		13.9 - 53.7
Residence B (Fireplace)	In	159.9	5.3	Only One Woodburning Day	40.9	2.9	21.7 - 66.9
	Out	30.3			14.0		7.3 - 21.8
Residence-C (Fireplace)	In	67.6	11.3	Only One Woodburning Day	18.8	1.1	6.3 - 39.0
	Out	6.0			17.9		7.7 - 30.5

EXHIBIT 8-29: RESIDENTIAL INDOOR AIR QUALITY AND WOOD COMBUSTION



INDOOR AND OUTDOOR 24-HOUR BAP CONCENTRATIONS AT RESIDENCE A

Source: D.J. Moschandras, et al., GEOMET Technologies, Inc. Residential Indoor Air Quality and Wood Combustion. Presented at Wood Heating Seminar, New Orleans, February, 1981.

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EXHIBIT 8-30: AMBIENT BaP CONCENTRATIONS IN VARIOUS LOCATIONS

Location	BaP Concentration (ng/m^3)
New York City, NY	0.3-3.5
Pasadena, CA	0.39-1.06
Karlsruhe, Germany	0.2-42.5
New York City, NY	1.15-1.30
Claremont, CA	.17-1.16
Toronto, Canada	0.1-0.8
Essen, Germany Residential coal heating area	6-60
Oil heating area	1.3-66
Auto tunnel	2-100
Vicinity of coke ovens	11-208
Rural location	0.5-8
Lake Michigan	0.3-1.8
Hamilton, Ontario	2.30-3.62
Los Angeles, CA	0.46
Chicago, IL	1.0
New York City, NY	0.9
Pittsburgh, PA	2.1
Tucson, AZ	0.4
Ashland, KY	4.7
Anchorage, AK	0.8
Denver, CO	2.2
Duluth, MN	1.1
Altoona, PA	19.3
Youngstown, OH	7.1
Coos County, NH	0.1

From several sources:
Wood Heating Seminar, New Orleans, La., February, 1981.
Ambient Air Assessment in a Rural New England Village Where Wood is the Dominant Fuel, Wood Heating Association, Washington, D.C., 1981, and James F. Hornig, et. al.

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The community regional state level air pollution potential of wood is suggested by Exhibit 8-31 which shows all states where more than 5% of any criterial pollutant from stationary sources is produced by wood burning. Three states -- New Hampshire, New York, and Vermont -- may already be running into a significant state-wide bood burning pollution problem. Particularly critical in this regard is that the particulates are associated with the POM or PHA, that is the carcinogen bearing materials.

EXHIBIT 8-31: PERCENT OF POLLUTANTS FROM STATIONARY SOURCES PRODUCED BY WOOD BURNING EMISSIONS

State	Particulates	HC	CO
Alabama			5.02
Alaska			9.08
Arizona			6.81
Georgia			5.08
Kentucky			5.69
Maine			30.48
Minnesota			5.05
Mississippi			7.02
Missouri			5.76
New Hampshire	25.34	6.75	28.39
New Mexico			6.21
New York	8.26		
Oregon			10.92
Tennessee			14.72
Vermont	14.82	8.11	27.53
Washington			6.63

Source: U.S. Environmental Protection Agency, "Source Assessment: Residential Combustion of Wood," EPA-600/2-80-042b. (1980).

The secondary impacts on air quality from increased wood burning are already being felt. Areas susceptible to atmospheric inversions and poor circulation, such as several small, valley towns in Vermont; Vail, Colorado; and Portland, Oregon are familiar with wood-induced smog.

Paraphrasing and extracting Cooper's summary of his own and others' research on the ambient air quality impacts of residential wood combustion, the following points seem important (53).

> On a moderately cold day in January, 1978, 51% of the respirable air particulates in a Portland, Oregon residential area were from RWC sources. One estimate is that about 4600 tons of mostly respirable particulates were emitted in 1978 in the Portland-Vancouver Air Quality Maintenance Area (AQMA) from RWC sources.

January emissions from this source would have been about 920 tons, while emissions from all other sources contributed only about 850 tons of respirable particulates.

Medford, Oregon and Missoula, Montana are both located in small valleys which experience frequent winter inversions trapping air pollutants. An estimated 215 tons of air particulates were emitted into the Medford airshed on an annual basis in 1977. RWC sources contribute between 20 and 30% of the air particulates in Medford annually. Even higher percentage contributions would be expected in the winter when the monthly average total suspended particulate levels exceed 200.

Almost 300 tons of air particulates were emitted annually in the Missoula valley in 1977 and would account for 40% of the winter TSP emissions and a much larger portion of the respirable particulates.

Surveys and modeling studies in Bangor, Maine, Chattanooga, Tennessee, Vail, Colorado, and the State of New Hampshire suggest significant emissions and high air quality impacts.

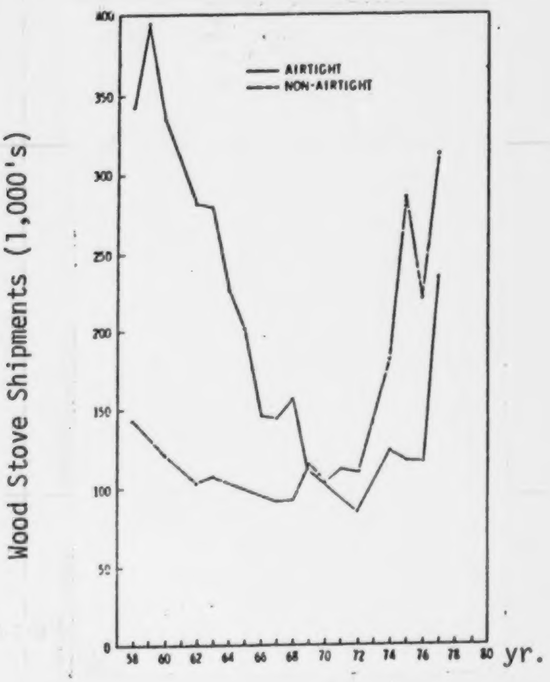
Perhaps as significant as the data themselves is the fact that EPA's local source severity analysis does not indicate these particulate problems, and hence some substantial revision in data collection at the local level may ultimately be called for.

Research by the Oregon Department of Environmental Quality suggests that a further problem aggravating the local outdoor pollution concentration may result from phenomenon they call downwash. Since stove and fireplace emissions are generally released only 15 meters or so above the ground, local turbulence may force those high concentration plumes to the ground (54).

The significance of all of these residential wood burning problems is heightened by the upward surge and sale of wood burning appliances since OPEC. Exhibit 8-32, from an EPA report, documents this increase in sales. Of course it is difficult to reliably conjecture as to the extent this trend will continue and hence imply opportunities for modifying a substantial number of yet to be sold stoves and furnaces, and to what extent sales will level off to leave a relatively saturated market, creating limited opportunities for retrofit and operational changes.

There have been several recent reviews and stocktakings of environmental and health effects of residential and other wood combustion systems: the Mittelhauser (19e) and the Aerospace Corporation (28) collations, both for the Department of Energy; a review article by John A. Cooper of the Oregon Graduate Center (53); and two closely related proceedings, one from the Wood Heating Seminar 1980-81 sponsored by the Wood Heating Alliance (55), and the Wood Combustion Environmental Assessment Proceedings sponsored by EPA in conjunction with the Wood Heating Alliance Conference (20a).

EXHIBIT 8-32: UNITED STATES PRODUCTION OF WOOD BURNING STOVES



Source: U.S. Environmental Protection Agency, "Source Assessment: Residential Combustion of Wood," (1980), EPA-600/2-80-042b.

The federal agencies have certainly not been indifferent to this potentially major new problem of residential wood combustion. The EPA research interests alone and in conjunction with TVA, as well as the Department of Energy's interests in these problems, are the principal sources from which the present subsection material is drawn. The research to date by no means establishes that there is a substantial health risk from residential wood combustion. The research, however, unequivocally establishes that the potential for such a risk exists and that a systematic well-structured research program is in order. It would address: the chemical characteristics of the wood emissions; the physical characteristics of alternative fireplace, stove, and furnace design; micro-meteorological characteristics of local ambient air pollution; biomedical effects of human exposure and the epidemiological data perhaps latent in studies and archives around the world.

Exhibit 8-33 shows a Department of Energy assessment of current data and research needs. While these are important and appropriate recommendations, we believe that the central issues, and the ones most needing immediate attention, are those related to polycyclic organic materials (POMs).

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EXHIBIT 8-33: RESIDENTIAL WOOD COMBUSTION: CURRENT RESEARCH AND FUTURE RESEARCH NEEDS

Research Activity Area	Adequacy of Current Data	Additional Research Requirements
HEALTH AND SAFETY		
Residential	Data available for accidents and deaths from woodburning units	• Evaluation of accident and death information from fires and burns and development of improved design, production, installation, and operational criteria for woodburning systems
	No data available for health impacts of indoor or areawide pollution	• Evaluation of acute and chronic adverse effects, such as morbidity and mortality from accidental burns and fires • Identification and assessment of causative agents, for example, health impacts from POM in wood emissions • Development of methods to reduce or eliminate harm when exposed to causative agents
2. General population	Inadequate	• Determination of the range of exposure that increased woodburning will produce, due to specific causative agents • Epidemiological studies of the incidence and distribution of diseases associated with increased air pollution in regions emphasizing residential woodburning
OVERALL INFORMATION AND DATA ANALYSIS		
1. Risk Analysis	Inadequate	• Economic and environmental analyses of using wood for residential applications • Determine relative risks of alternative residential heating options
AIR POLLUTION		
1. Woodburning source characterization, measurement, and monitoring	Characterization partially adequate; inadequate for measurement and monitoring	• Characterization, measurement, and monitoring of unburned combustible particulates (fine breathable), hydrocarbons, carbon monoxide, sulfur oxides, nitrogen oxides, aldehydes, and POM (for both current and advanced burners) • Analysis of design and construction criteria to lower combustion emissions • Development of improved operation criteria • Overall assessment of wood fuel chemical characterization and relationship to emissions • Evaluation of influence on photochemical oxidant/ozone formation • Determine the number of woodstoves/acre or amount of fuel burned/acre
2. Measurement of indoor pollution	Inadequate	• Characterization and health impact assessment of wood combustion emissions in indoor environment in combination with other indoor emissions
3. Measurement of ambient regional pollution	Inadequate; few regional assessments have been made (Portland and TVA)	• Characterization, modeling of transportation and dispersion, and assessment in regions where high density residential woodburning is occuring and will occur, include National Ambient Air Quality Standards, visibility, PSD, etc., impacts • Health assessment studies of wood combustion pollutants in regions that are in nonattainment status especially due to particulate violations • Development of ambient fine particulate, aldehyde, and POM measurements to determine actual population exposure

Source: U.S. Department of Energy. Health Effects of Residential Combustion: Survey of Knowledge and Research. Report DOE/EV-0114 UC586. September 1980.

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Inappropriate and Dangerous Residential Fuels

An area of concern which has been overlooked in the literature, and which should be monitored, is the question of substitute fuels. The first example of this would be the burning of coal as a substitute for wood. If the stove is not designed to burn coal, there is danger, because of the more intense fire of stove burn-out, that is, a hole being burned through the stove wall or bottom. Coal, as noted earlier, emits enormous quantites of particulates and POMs, potentially a serious hazard to the operator. The problems of coal substitution are relatively well known, but the same cannot be said for many substances likely to be burned when the woodbox is low. There will be a temptation to burn scrap wood from demolition which may contain lead, arsenic, or other toxic materials. Wood treated with preservatives such as pentachlogophenol will undoubtedly burn to produce hydrochloric acid and other perhaps more toxic gases. Rolled newsprint, plastics, and used crank-case oil are other examples of risky substitutes. This last substitute came to one author's attention during an informal interview with a rural mechanic in Minnesota. This mechanic augmented his space heating with a home-made wood stove made from two 55-gallon drums stacked on top of each other and vented to the outside. This was particularly interesting because, in addtion to burning wood, the man had attached a supply of used engine crankcase oil to his stove. The oil was fed by drop lines to a petcock and then into the stove. Presumably the number and type of particulates coming out of that smoky stove included many of the organic and inorganic compounds used as additives in motor oil. When questioned as to whether this was risky, he replied, "The smoke may be, but it's all outside."

The scope of this problem is unknown; it will almost certainly be real. Its biggest effects, moreover, will be on the impoverished and ignorant, the urban and rural poor.

Some Action Choices

Assuming that the force of the data, so far, on health risks from residential wood combustion will be borne out by further laboratory and field work, the situation would create a public policy dilemma for the Environmental Protection Agency. The present legal and regulatory framework, notably the Clean Air Act, does not seem to provide the basis for regulation of stoves and fireplaces by EPA. Even assuming, however, that the power existed, it is not all clear that it would be desirable to attempt a direct regulatory and enforcement approach. The technology is diffuse. It would be extremely difficult to enforce any rules except those which implied measurable changes in the physical characteristics of stoves in commerce. Attempt to initiate domestically intrusive regulations would meet strong, vigorous resistance from the public and might go a substantial distance toward undercutting the presently growing positive relationship between EPA and the industry. As previously noted, there seems to be a positive and healthy relationship between the stove manufacturers, notably the members of the Wood Heating Alliance and the EPA laboratories in North Carolina, in which mutual support is being given through the environmental research program on residential wood burning at the laboratory. The industry wants to improve the quality of its own products, and it seems therefore that this as an organizational administrative novelty is to be encouraged as a potential model for dealing with other new environmental problems.

Among the range of policy options open to EPA and meriting more detailed evaluation are:

- certification
- incentives
- inspections
- public information and education
- knowledge generation, especially research and field monitoring
- performance ratings
- cooperative research
- the support of private sector evaluation and standards setting.

Exhibit 8-34 outlines regulatory implications in terms of existing legislation.

SUBSTITUTION EFFECTS OF EXPANDED WOOD USE

If more wood is used as an energy source, then either absolutely or relatively less of some other energy source will be used. In other words, wood would substitute for something else. But what it will substitute for is unclear. It is national policy to reduce dependency on foreign oil. Consequently, one could see any growth in the use of biomass as being a substitute for foreign oil dependency. On the other hand, the decline in foreign oil imports could be met by an increase in coal, domestic oil and gas production, or nuclear power. It is the view of this report that the overwhelming national need in a stated national objective is to reduce dependency on foreign oil. As expressed earlier, there is a growing consensus among policy analysts that a diversified energy base consisting of solar, geothermal, wood, greater conservation, and other supplies would be more desirable than a shift toward dependency upon some dominant alternative, such as coal or nuclear. On the other hand, on a regional basis, one could always argue that any decision maker, any utility, any factory, and home has a decision to make between some competing contenders. It furthermore is the case, as argued in Section 3, that wood or any other new and unfamiliar technology is unlikely to effectively compete against well established technologies with well established routes for delivery, well established technologies for fuel preparation, or well established technologies for energy conservation, unless specific policy measures are taken to assure that the competition is put on a fair footing in the short and long-term. The net conclusion from the points raised above is that one cannot determine by any clear and independent standard what it is that biomass is competing with. Therefore, some comparison with coal, in terms of major environmental risks, might be useful. Fortunately, we can draw on the already digested results of the OTA study in this regard. (See Exhibit 8-35). We reject any argument that environmental effects are or could be, or should be, the dominant consideration in any choice between biomass and coal. The overwhelming consideration at the national level should be independence from foreign imports and stability of energy

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EXHIBIT 8-34: REGULATORY IMPLICATIONS OF WOOD COMBUSTION SYSTEMS

Legislation	Applicable Pollutant or Residuals	Standards (Current or Proposed
Water Pollution Control Act (continued)	Nonpoint source discharges are regulated under section 208 of the act.	Each water quality planning region is required to identify the priority sources of nonpoint discharge in the region and to prepare plans for their control.
Thermal Discharges	Basis of regulation is to minimize the impact of thermal discharges on the receiving waters' overall ecosystem balance.	The limitations of the regulation are generally determined by the state agencies for site-specific applications.
Occupational Safety and Health Act	Aim is to limit worker exposure to various regulated chemicals. Regulations also include considerations for worker safety in the workplace.	Logging is considered a high-risk occupation and often subject to inspection and regulation.
Resource Conservation and Recovery Act	Hazardous solid waste must be monitored.	Treatment to minimize the impact on local water resources must be performed. Often this treatment consists of chemical adjustment, dewatering, and containment of solids.
1897 USFS Organic Act 1960 Multiple Use Act 1976 National Forest Management Act	Irreversible damage to soil and water and sustaining forest yield could result.	Collectively they provide authority to the Forest Service to regulate the allowable cut and the conditions of harvesting.
National Environmental Policy Act	The environmental impact of Federal projects must be analyzed.	An Environmental Assessment or Environmental Impact Statement will be prepared and reviewed.
Federal Endangered Species Act	Habitat of threatened or endangered species could be damaged.	The Endangered Species Commission of the Department of the Interior will review the Environmental Assessment or Environmental Impact Statement for harvesting on Federal lands. The Commission can approve or disapprove the harvesting plan to the extent that it affects the endangered species.
Clean Air Act	This legislation will have a major impact for criteria pollutants. Based on the ambient air quality, most regions of the United States are evaluated as either nonattainment or clean. The major wood-growing regions are remotely located in clean air quality areas and therefore fall under the Prevention of Significant Deterioration (PSD) Regulations of the act. The act limits the degree of air quality degradation in PSD areas as a function of general industrial activity. The pollutant of immediate concern is particulate emissions and accompanying visibility reductions. Other pollutants regulated by ambient air quality standards include carbon monoxide, photochemical oxidants, sulfur dioxide, nitrogen oxides, and hydrocarbons.	New Source Performance Standards are currently proposed for large utility stations generally considered larger than economically attractive for wood firing (greater than 250 million Btu per hour heat input). Depending upon the specific location, ambient air quality degradation would be regulated by the PSD permit allowables.
Water Pollution Control Act	For industrial applications, pollutant concentrations are regulated by the National Pollutant Discharge Elimination System (NPDES) Permits. For the utility industry, wood combustion would probably fall under the "small unit" subcategory. The list of pollutants regulated include free available chlorine, total suspended solids, oil and grease, copper, and iron.	Regulations are as required by the discharge limitations for the specific industry. The regulations distinguish between existing and new sources and also if the discharge is sent to a publicly owned treatment plant rather than to a receiving stream. The regulations also distinguish between the many sources within a power plant such as low volume wastes, bottom ash and fly ash, transport water, metal cleaning, and boiler and cooling tower blowdown.

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Source: Mittlehauser Corporation. Wood Combustion Systems: Status of Environmental Concerns. Report DOE/EV-0064 UC-61 for the U.S. Department of Energy, January, 1980.

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EXHIBIT 8-35: MAJOR ENVIRONMENTAL RISKS - COMPARISON OF BIOMASS AND COAL FUEL CYCLES*

	Biomass	Coal
Land	Large land areas permanently affected: • ecosystem displacement and loss of diversity, • erosion, • esthetic changes, and • possible soil depletion over the long term.	Smaller land areas affected at any one time: • reclamation failure and subsidence, and • erosion.
Water	• Biological and chemical oxygen demand from fertilizers and conversion wastes. • Sediments—major problem without careful management. • Pesticides.	• Toxic substances from ash and sludge disposal, synfuels production. • Acid mine drainage (but generally well controlled now). • Sediments—more localized, effect of new surface mine law not yet determined.
Air	• Local problems with unburned hydrocarbons, particulates, CO, H_2S, odors.	• Local dust problems (mines). • Problems associated with long-distance transport of sulfur and nitrogen compounds, fine particulates, and possibly oxidants (acid rain; health effects—possibly including excess deaths; crop damage; visibility degradation). • Possibility of climate changes from CO_2 emissions.
Institutional	Regulatory difficulties with: • multiple small sources and • nonpoint sources.	• Very expensive controls, especially for air pollution. • More centralized systems, may be more amenable to regulation under current programs.
Safety	• Significant problems with obtaining feedstocks and with small-scale conversion, especially wood stoves.	• Significant problems with mining, especially underground.

*Source: Office of Technology Assessment, Vol. 1, p. 55.

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supply. At the local level, the microeconomics should drive the decision. Nevertheless, the comparison between wood's and coal's environmental effects is useful.

Consider Exhibit 8-35. As already discussed, the knowledge of the forest is too inadequate to understand the long-term implications of a two- to five-fold increase in biomass for energy. But questions of erosion, nutrient loss, downstream effects on sediments, entrification, flooding, are real considerations meriting close understanding. One difficulty to keep in mind in making these macro-scale comparisons is that the knowledge of the problems with coal are far better established than the knowledge of the equivalent effects on land and water of extensive use of biomass.

In terms of air effects, the use of biomass in central power stations does not seem to present any significant problems. The use at residential levels is far more significant, as discussed earlier in the present text. From the point of view of wood, the institutional problems are no different for central power station consumption, although there are major institutional problems at the forest management side. On the use side in combustion we are in good shape with regard to central power station use. The problems will be fewer and simpler. However, the problems in residential use as non-point sources will cause institutional issues. In terms of health and safety, as wood burning comes into larger play, many people burning wood in residences may choose for a variety of reasons -- cost, convenience, and so on -- to attempt to use coal as a backup. This will increase safety problems and further exacerbate the institutional difficulties of air pollution control.

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The predominant safety problem as expanded in our text, above, is from residential burning, producing large amounts of smoke, POMs, with the added safety hazard of burning contaminated scrap wood.

The risks to human safety in mining and lumbering are roughly comparable. Both are dangerous occupations. The safety risks from more distributed use of coal and wood in residences are likely to be relatively greater than those from the equivalent amount of heat from a central power station, either used directly or in the form of electricity. However, one can see the residential problems as a social learning process. With the passage of time, in much the way we have learned to use gas stoves and electricity at home safely, we can expect to learn to use the new wood stoves more safely.

We see no point in expanding the discussion of the comparison among fuels from an environmental point of view, since we do not believe that is, could, or should be a dominant driver in any set of social choices. The arguments are against nuclear, not for wood. The arguments are against foreign oil, not for wood. The arguments are for conservation, not for wood substitution.

A second kind of substitution which is implicit in biomass, but more closely associated with agricultural rather than wood wastes, are the substitutions on the farm of the gasifier or anaerobic biogas generator for purchased energy. The principal substitution advantages there are micro-economic in potentially providing the farmer or the farm community with an alternative, stable, cheaper source of supply. Secondly, a local source provides a buffer against price excursions, and thirdly, would provide an incidental benefit in helping to clear up some troublesome or otherwise useless waste.

A third aspect of substitution has already been mentioned, which is of particular concern to the forest products industry as a consequence of poorly planned Federal interventions. Should an artificial price structure be set for wood which would upset the market for current paper and hard products, the principal product of the forest products industry, by favoring wood for energy, by net effect might be to draw many more energy and resource intensive materials such as aluminum and plastic into the market to substitute for wood. It is conceivable, therefore, that there be a net energy expenditure rather than saving as a result of market disruption.

CAPABILITIES IMPLICIT IN THE MORE EXTENSIVE USE OF BIOMASS

As discussed in Appendix A, one of the principal historically confirmed causes of technoeconomic and social change has to do with capabilities implicit in a new technology. Those capabilities are often either ignored or are of only minor importance at the time the technology is introduced. Several consequences of the long-term successful doubling to quintupling of wood resources for energy relate to new capabilities. First, we would have to develop a better capability to manage forests and a better knowledge base for that management. That knowledge would also be useful to other advanced industrial nations to the Third and Fourth Worlds, in their own silviculture planning.

A second capability which seems to have high likelihood of becoming more important in wood use is densified and pelletized wood. The capabilities will expand the market for wood and make it more directly competitive with coal in the cost of transportation and the ease of handling. It may also open up foreign urban markets in those parts of the world pressed for firewood.

The most significant capability associated with the ability to transport wood for energy generation may be the development of a new chemical industry. The use of wood as a chemical feedstock could follow two main channels which are not mutually exclusive, but do have different potential enivironmental, health, and safety implications. One route would be for wood stock to become a new source of those organic chemicals already dominant as petrochemicals. As already discussed, technically there are no limitations on the production of methanol from wood.

There is no limitation on the production of synthetic gas and associated Fischer-Tropsch reactions for the production of motor fuel from hydrogen and carbon monoxide. Should that route be followed, the principal impacts on the environment would not be the impacts of the end product, but would be on the demands for even more wood as raw material. There might also be site specific implications of the expanded production of those chemicals. There would also be some new twists and kinks in waste management, but nothing exceptional is likely to arise from that route.

It is the second alternative which is far more interesting . As the capabilities implicit in the large-scale handling of wood develop, there will be incentives to use wood chemicals themselves as a basis for organic chemicals, polymers, and the scores of other synthetic chemicals now common as articles of commerce. From a chemical point of view, wood is composed mostly of cellulose and lignin. Cellulose is now widely used and it will be increasingly used as a source of alcohol through processes of thermochemical or enzymatic hydrolysis followed by fermentation to ethyl alcohol. This is an example of the first course described above. The example of the second course would be the use of cellulose and cellulose additives directly as a basis for new chemical products. While some such products are known, such as carboxymethylcellulose, rayon, celluloid (now an obsolete material), and others, the possibility of cellulose base in the chemical industry is real. The other major component, the lignins and the hemicelluloses, could also form bases of families of large volume chemicals.

As we see it, we are now so far back in the R of the R&D cycle and in the use cycle with regard to these chemicals that only a few critical questions would be worth addressing from the point of view as to whether public policy should remain neutral, discourage or encourage the further development of wood derived chemicals.

Cellulose, lignin, and lignocellulose are without doubt the largest bulk organic chemicals on earth. Yet relatively little use is made of them as chemicals. From many plants and trees one derives a class of chemicals known as terpenes. These are hydrocarbons that are readily transformed into hundreds of other compounds. This implies not the same line of development we now see in petroleum based chemicals, but by being structurally different they imply the development of chemicals of an entirely different sort. Starch, sucrose, sorbitol, fatty alcohols, furfural, tetrahydrofuran, dimethylsulfoxide, vanillin, and scores of other materials from azelaic acid to xanthan gum are available from plant sources. Exhibit 8-36 shows a number of chemicals from wood. Those not readily prepared by alternate routes are asterisked.

There is a tremendous appeal in these biologically generated materials in that a fundamental law of nature is that what nature creates biologically nature can destroy biologically. Nature knows no permanently indestructible organic materials. Consequently, one would anticipate that these organically derived materials, being naturally derived, would be environmentally more benign and more readily metabolized. Consequently, one could see a chemical industry based upon these natural products being intrinsically more environmentally acceptable.

The reverse side of the coin, and one carrying a potential forbidding danger, is that to convert many of these materials to commercial products we would employ processes of bromination, chlorination, fluorination, oxidation, hydroxylation, epoxidation, and the scores of other processes that give us contemporary petrochemical products. The very fact that these basic molecules are more readily metabolized may imply that when treated to make these new chemicals, they would become antimetabolites -- that is, they would block the processes of degradation in nature and create massive risks to all kinds of micro- and macro-organisms.

The resolution of the question of the general environmental desirability of biomass-based chemicals merits some laboratory attention of EPA to determine whether it is in the long-term interest of the nation to encourage or discourage a movement from petroleum-based to plant-based chemicals.

The future of biomass derived organic chemicals is covered in some preliminary detail in the CHEMRAWN 1 Conference.

THE NATIONAL FOREST ENERGY PROGRAM

In order to provide some administrative context for the recommendations presented in Section 1, the National Energy Program for Forestry, as defined by the U.S. Forest Service publication 1394, October 1980, is displayed in Exhibit 8-37. It is beyond the scope of the present work to review in any detail the budget allocations and long-range plans supporting this program. We have in our own recommendations, however, highlighted critical questions, whether or not they seem to be subsumed under the present program goals, in order that EPA, the primary client for this report, have specific points of inquiry in its interagency coordination.

EXHIBIT 8-36: CHEMICALS FROM WOOD

ETHANOL FROM BIOMASS BY FERMENTATION

- Ethanol From Molasses
- Ethanol by Acid Hydrolysis of Wood
- Ethanol by Enzymatic Hydrolysis of Cellulose

ETHANOL DERIVATIVES

- Ethylene from Ethanol
- Acetaldehyde from Ethanol
- Butanol from Acetaldehyde
- Butadiene

OTHER INDUSTRIAL FERMENTATIONS

- Acetone/Butanol Fermentation
- Citric Acid
- Gluconates
- Itaconic Acid
- Lactic Acid from Molasses
- Xanthan Gum*

CHEMICALS FROM SUGARS*

- Sorbitol
- Sucrose Surfactant

STARCH POLYMERS*

- Hydroxyethl Starch Ether*
- Absorbant Starch Crylonitrile Graft Copolymer*

FROM HARDWOODS

- Methanol
- Pentasans

CHEMICALS FROM OILSEEDS*

- Fatty Acids from Vegetable Oils
- Fatty Alcohols
- Glycerol
- Soap
- Azelaic and Perlargonic Acids
- Nylon-11
- Jojoba Oil

FURFURAL AND DERIVATIVES*

- Furfural
- Furfural
- Tetrahydrofuran

CELLULOSE POLYMERS*

- Carboxymethylcellulose (CMC)
- Rayon
- Cellophane
- Cellulose Acetate

PRODUCTS FROM PULPING WASTES

- Acetic/formic Acid from NSSC Black Liquor
- Dimethylsulfoxide
- Lignosulfonates*
- Tall Oil Fractionation*
- Vanillin*

FROM SOFTWOODS

- Turpentine*
- Rosin*
- Pine Oil*
- Rosin Oil*
- Pitch*
- Pinetar*

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*Not readily available from non-vegetable sources.

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EXHIBIT 8-37: A NATIONAL ENERGY PROGRAM - PROPOSED FRAMEWORK FOR A NATIONAL PROGRAM

Energy goals established by the U.S. Department of Agriculture formed the basis for the Forest Service's forest biomass energy program described in this brochure. In establishing objectives for the program, the Forest Service identified needs and actions to reach the objectives.

Goals
In 1976, the U.S. Department of Agriculture identified the following goals to help solve the Nation's energy problems:

1. Assure energy supplies for essential food, fiber, and forest production.

2. Provide maximum support to short- and long-term energy conservation.

3. Develop the energy potentials of biological materials and wastes.

4. Facilitate the environmentally sound development of energy reserves of coal and other resources on Federal lands.

In 1979, the Secretary of Agriculture identified a fifth USDA goal—support activities to assure that agriculture and forestry become energy self-sufficient by 1990.

Objectives
To help attain these energy *goals* of the U.S. Department of Agriculture, the Forest Service proposes a forest biomass energy program with the following *objectives*.

1. Production annually of 6.4 quads of energy from forest biomass by 1990.

2. Conservation annually of 2.0 quads of energy by 1990 through improved efficiency in the production and use of wood products.

3. Development and implementation of environmental protection guidelines in connection with production and use of wood for energy.

Production. To meet the production objective, we need to consider the following five categories of needs:

1. *Current and accurate resource information.*—Current inventory procedures do not measure total biomass. We need more accurate estimates on biomass available by class of material and location. Measurement of total biomass must be incorporated into traditional inventory procedures. We also need methodologies for measuring and determining the volume of biomass and converting current data to biomass weights. Techniques to estimate biomass weights for site specific feasibility studies need to be developed.

To meet these needs the following *actions* are proposed:

- Develop techniques to measure and classify biomass and prepare volume and weight tables.
- Prepare regional biomass estimates and identify the best potential uses.
- Incorporate biomass volume and weight measurement into inventory procedures.
- Develop regional wood supply and demand models.

2. *Improved forest management.*—Current productivity on commercial forest lands is far below the potential. A much greater effort is needed to transfer existing forest management knowledge to both large and small landowners. Research is needed to improve our knowledge of management alternatives especially related to energy products.

To meet these needs, the following *actions* are proposed:

- Identify and develop silvicultural and management techniques for maximizing biomass production in natural stands.
- Increase the information base for species adaptable to intensive-culture, short-rotation forestry.
- Establish test plantations of selected species.
- Increase technical assistance to private forest landowners.

3. *Recovery of forest biomass.*—Increasing productivity of our forests is of little value unless the wood is harvested, processed, and delivered to the user at a reasonable or competitive price. Current equipment and systems were designed principally for large and relatively uniform logs and cannot be expected to recover efficiently much of the existing forest residues. We need considerable testing and modification of current equipment and systems, coupled with research and development of new equipment and systems to recover large volumes of wood economically. Timber sale procedures need to be modified and new approaches to contracting for stand improvement and fire prevention practices need to be developed. Also essential are programs to encourage wise production of fuelwood from private lands.

To meet these needs, the following *actions* are proposed:

- Test various configurations of systems that use existing equipment to establish a cost base for harvesting and transportation.
- Develop and test new and modified equipment to improve efficiency in handling residues and small trees.
- Identify and describe specific sites, stands, and conditions requiring special logging systems and equipment.
- Develop specialized equipment and systems.
- Develop and implement improved in-woods processing and transportation systems.
- Develop and implement improved processing, handling, drying, and storing systems.

Source: U.S. Dept. of Agriculture, Forest Service., Misc. Publication No. 1394

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EXHIBIT 8-37, continued

4. *Substitution of petrochemicals and fuels with biomass-derived counterparts.*—Most of our critical consumer industrial chemicals are derived from petroleum. Fuels essential for our transportation systems also come from petroleum. We need to find substitutes so that we can reduce our reliance on foreign petroleum. Basic and applied research is needed so that conversion of forest biomass to chemicals and alcohols can become economically feasible.

To meet these needs, the following *actions* are proposed:

- Develop energy-efficient methods to improve the yield of alcohol from wood.
- Develop procedures for increasing the feasibility of producing alcohols at pulp mills.
- Conduct basic research to develop petrochemical substitutes such as adhesives from wood and bark.
- Expand the use of technology for increasing the production of oleoresin from southern pines.
- Develop improved pyrolysis systems for producing oil, gas, and charcoal.
- Establish alcohol pilot plants to utilize wood biomass as the primary feedstock and/or fuel.
- Establish small-scale pilot plants and distribution systems for on-farm or community production of alcohol from biomass.

5. *Stimulating increased use of wood fuel.*—Heating the home with wood is different from what it used to be in the late 1800's. Today, we need to consider new designs for circulatory heating systems, homes unoccupied for 8 to 9 hours at a time, much higher prices for wood, stringent building codes, and potentially higher insurance rates.

The use of wood by industry must consider other factors, such as large fuel supply requirements, meeting environmental concerns, costs, methods for handling of large volumes of material, facilities for burning nonuniform fuel—such as forest biomass, unused mill waste, and urban and land clearing residues—and systems for collecting these residues economically.

To meet these needs, the following *actions* are proposed:

- Identify specific market opportunities for unused wood and develop strategies to attract the interest of these markets.
- Develop and implement reliable merchandising schemes to supply the growing demand for residential fuelwood.
- Develop efficient and convenient residential heat plants.
- Develop reliable wood gasifiers.
- Develop improved handling and processing procedures for biomass feedstock.
- Develop guidelines for the safe installation and use of home wood burning appliances.

Conservation. The conservation of energy in all activities, from the establishment of forest stands to the use of forest products by the consumer, can save significant amounts of energy. The proposed options, if adopted, could result in saving 2 quads of energy annually by the year 1990.

(Details omitted)

Environmental Protection. Increased production of wood for energy need not be made at the expense of environmental quality. The increased use of wood for energy offers positive forest management benefits. The reduction in the volumes of logging residues will decrease the slash-related fire problem. The thinning of timber stands will increase the growth rate and productivity and shorten the rotation period for pulp and sawlog production. However, research has not fully evaluated the results of increased removal of biomass. We need hard facts concerning the impact on soil, water, wildlife, and other amenities of the forest ecosystem that results from increased utilization of wood from different forest sites. We also need to know more about the potential pollution problems that can result from the increased use of wood stoves in homes. Technical assistance is needed by landowners and wood producers so that environmentally sound land management and cutting practices are used.

To meet these needs, the following *actions* are proposed:

- Accelerate research to develop environmental guidelines for the management of the different forest types and sites that will be harvested for energy wood.
- Increase the technical assistance available to small land owners.
- Develop efficient wood burning systems to reduce the adverse effects on air quality.
- Initiate public information programs on forest management and the efficient use of wood directed at landowners, commercial firewood producers, and users.

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SECTION 9

ATTITUDES AND CONFLICTS

PREVIEW

This section deals with public and institutional attitudes toward the use of forests for biomass energy. It also highlights conflicts whose resolution will determine the speed and the extent to which woodland resources are used in achieving a new national energy balance, with adequate safeguards to people, their environment, and the technoeconomy.

INTRODUCTION

There is a common tendency to see present attitudes as more durable than the historical evidence suggests. Consequently, we turn first to the matter of public attitudes toward the forest and what this implies for future change. Then, focusing on some principal conflicts, we highlight core issues whose resolution will require the attention of public policy makers and whose resolution is key to how and how much biomass energy is used. Anticipating several points in that conflict, it is worth noting that the forest products industry's principal positive concern is the use of wood energy within the industry. On the other hand, there is an extensive fear that government intervention to promote wood energy will upset the price structure of the industry's principal products -- paper, lumber, veneer, plywood, particle board, and other manufactured materials. A serious conflict is between the need for integrated approaches to resource utilization and a fractionated and fractious public authority. There is also conflict between the needs for integrated approaches and a widespread turning away from government intervention.

LONG-TERM PATTERNS OF PUBLIC ATTITUDES TOWARD FORESTS

Three periods of attitude and behavior toward the American forests have been noted by the historian Samuel Hays of the University of Pittsburgh. (1)

In the first period -- from the nation's beginning to the late 1800s -- settlers saw the forest as a threatening environment and an impediment to the march of civilization. The forest was prized for what it would yield immediately; few thought of it as a permanent part of an evolving society. There were no forest managers in the sense that we know them today; forest use was dominated by individual entrepreneurs who were experts in timber extraction, not land management. Forest communities were strongly linked to the fortunes of these entrepreneurs -- the communities were a temporary adjunct of the extractive economy and made an uneasy transition to serving the farmers who tried to wrest a living from the newly cleared land. This attitude is close to that of many in the Third World today -- saw now, worry later.

The second, or custodial period, lasted from the late 1800s through World War II. This saw the rise of no less than six public forest systems --

dominated by the national forests -- plus the private industrial forests. The six are:

- national and state parks
- state and federal game lands
- northeastern state and county forest lands
- western state trust lands
- O & C lands, later managed by the Bureau of Land Management
- the national forests

During this period, there was a changing public perception of the forest -- from an environment to be eliminated to one which had sustained value. More visitors came to the forests as the old logging camps were transformed into hunting and fishing resorts and the great camp dining hall to the housekeeping cottage. In the South and East, farm communities came to recognize that sustained wood production offered greater long-run economic stability than did marginal agriculture. In the West, communities advocated forest protection to safeguard water supplies. Public land managers were custodians emphasizing reforestation and protection against fire. In the economic collapse of the Great Depression, many communities opted for permanent state and federal ownership of surrounding forest land, in hope that it would sustain their economies and their civic life. That was the era of extensive federal forest acquisition in the East.

Since World War II, the third period, Hays finds forest history dominated by two trends: widespread interest of the public in the use of forest land on one hand, and the development of increasingly more intensive management on the other. The national forests were engulfed by a host of uses and users. The "forest as environment" became an alternative view of the forest, to compete with the older commodity viewpoint as the basis for forest management.

With the drive for increased timber production and burgeoning public use of the forests, management shifted from the custodial approach to greater investments of money and skills to achieve ever more intensive outputs, says Hays. The Forest Service attempted intensive management by categorizing land and separating uses. The industrial forest managers perfected intensive forestry to produce wood. A major schism developed between managers whose objective was to produce wood and advocates of environmental forest management.

Writes Hays: "After World War II, discovery of the nation's wildlands by an increasing number of people led to an intensity of human involvement in the forested environment unknown earlier... People discovered natural lands and came to know them personally by hiking through them, observing them closely, photographing them... Through such personal involvement these areas came to be thought of as one's own 'turf,' to be known, enjoyed, described, communicated and protected." And across the nation, forested lands became an integral part of community economies -- sometimes for the timber they produced, in other places for a new economy of recreation, leisure, travel and tourism, says Hays. "Even where wood production remained important it had to share its role with new forest uses."

Hays concludes: "If there is a historical guidance to our current task of formulating forest policy, it can be found not in the remote past, but in the massive changes in human perceptions of the forest which have taken place in the more recent thirty years."

As we see it, since 1960 and the passage of the Multiple-Use-Sustained-Yield Act, multiple use has dominated Forest Service thinking.

For that 70% or so of forest in private hands, Forest Service thinking is a direct and indirect factor in their management. For small landholders the Forest Service is a test bed, a model, a developer of new technologies and skills, a technology transfer agent, and a source of guidance. For the larger landholders, the corporate landholders, it provides some similar functions, but more importantly, it raises to the level of demonstration alternatives and choices which are perhaps not fully within the framework of all corporate thinkers. It should, of course, be noted and emphasized throughout this report, that the large corporate landholders have an implicit long-term interest in good long-term management.

Emerging Attitudes

Hays has not speculated on emerging attitudes. It seems to the present authors, however, that the United States is entering a new era of comprehensive generation and use of scientific and technological knowledge and skills in the planning and management of forests. One can see the leading edge of these concerns in the growth of ecological concerns, the potential for traditional and new forms of genetic manipulation, the awareness of incidental and derivative effects of overutilization of forest lands, and the broad sweeping attention to developing that new level of understanding. One can see us moving from maintenance of an integrated patchwork, to a holistic and comprehensive attitude toward forests.

The Forest Products Industry View of Wood Energy

There has been a consistent strain of negativism in the industry toward the use of wood as a major national energy resource outside the forest products industry. The argument hinges around two points. One is that the forest products industry as it seeks to become more energy independent of external sources will be using more wood energy itself. The second argument is that silviculture management for energy and the high levels of removal required -- transportation and so on -- make wood an economically unattractive source of fuel compared to coal and nuclear. These two points converge on a third point which is surely the core of the industry's objection -- the use of large amounts of energy from forest products could economically disrupt the traditional wood products/paper products sectors. There are enough incontrovertible illustrations of government intervention upsetting traditional and established economics, that this is neither a trivial nor illegitimate concern.

T. Marshall Hahn, President of Georgia-Pacific Corporation, expressed this clearly in his remarks to Bio-Energy 80, the World Congress and Exposition in Bioenergy.

> Use of wood for fuel has been growing rapidly in recent years because of higher prices for oil and natural gas. The forest products industry has been particularly active in expanding its use of wood residues for fuel and accounts for most wood-generated energy. Georgia-Pacific Corporation is involved in many wood energy projects and was 62 percent self-sufficient in its building products and papermaking operations in 1979. Wood, however, cannot play a major role in solving U. S. energy problems, although as a renewable resource it can make a substantial long-term contribution. The forces of the marketplace will best determine wood's optimum uses, which currently include building products, pulp and paper, and chemicals, as well as energy. The marketplace best accommodates for net energy benefit (after collection and conversion) as well as alternative uses. Subsidies to increase the use of wood for fuel could cause misallocation of this already scarce resource and establish an uneconomic, artificial market that would require continuing support. Coal and uranium are currently the only two alternative sources capable of playing a major role. Both should be developed, particularly nuclear power, which has an impressive record of safety. The same mentality that objects to nuclear power is also impeding forest management and will ultimately present problems for the emerging bio-energy industry. (2)

Energy use is currently the lowest economic priority for the use of wood, simply because the industry has traditionally harvested the merchantable wood and tended to leave the residues in the forest. Merchantable wood has, of course, been premised around meeting established markets for lumber, paper, veneer, plywood particle board, etc. As this report has made amply clear, the residues in the forest have a vast potential for energy exploitation. There is no reason to believe, in principle or in fact, that the harvesting of those residues and/or the establishment of forests significantly or primarily dedicated to energy rather than to other products, are incompatible with the established long-term interest of the forest products industries.

A Trade Association Perspective

A detailed and specific set of anticipations of the effects of the energy situation on the pulpwood industry, a major sector of the forest products industry, has been put forward by the American Pulpwood Association in an April 1980 report. The key changes that would occur in business strategies and further changes that would occur if new entrants came into the wood market are displayed in Exhibit 9-1. Some of the more negative economic

EXHIBIT 9-1: EFFECTS OF THE ENERGY SITUATION ON THE PULPWOOD INDUSTRY *

Changes That May Occur in Business Strategies.

Condition 1.1 - More centralized merchandizing and processing centers for wood products will appear where many operations can be "energized" from a central power plant. This will make use of economies of scale and energy conservation techniques.

Condition 1.2 - As fossil fuel prices increase, the value of wood fuel will increase as well. When the price of wood fuel approaches an existing value of pulpwood, the pulpwood costs will rise to stay ahead of fuel wood prices.

Condition 1.3 - The forest products industry will consider and install multi-fuel boilers where possible. Fuel flexibility is the key to effective energy crisis management in the future.

Condition 1.4 - In the short run, many forest products based companies will not be able to convert their boilers rapidly to multi-fuel boilers capable of burning wood. Therefore, fossil fuels will continue to be extremely important to the industry for the near future.

Condition 1.5 - The paper mill of the future will run on residuals. It is becoming increasingly difficult to justify growing primary fiber solely for a paper mill. Increasing costs of stumpage, merchandizing, and energy demand that products must be used for the highest and best use.

Changes That Will Occur Due to New Entrants in the Wood Market

Condition 2.1 - In the future, fossil fuel shortages and high costs will increase, and bring about increased utility generation of power by wood and increased home use of wood for heat. These increases will impact heavily on local energy wood procurement markets and have the effect of expanding local procurement areas to the maximum economic haul distance.

Condition 2.2 - If the pulpwood industry fails to enter the fuel wood business other entrepreneurial interests will. Land based companies will probably attempt to meet their own needs first; and should then, in the public/national interest, become a source of supply of energy wood.

Condition 2.3 - Nonforest based companies in their search for wood for fuel will compete in wood markets in localized areas. Areas around population centers will reflect market pressures first.

Condition 2.4 - As other users get into the energy wood business, then those forest based companies without strategic wood energy plans will have an increasingly hard time competing for wood energy products. Forest based companies with a land base should be able to provide a greater portion of their own wood fuel requirements from company land and company purchased stumpage.

Condition 2.5 - Chip upgrading by screening and segregation will have two beneficial effects: (1) a higher quality product will be produced, (2) residual wood will be segregated that can be burned for energy wood.

Condition 2.6 - Increased use of residuals for fiber in pulpmills works against mill bark use for energy wood. In 1977 65% of our total energy wood demands were being met by bark from debarking drums. However, this percentage will decrease as the industry continues to go to use of more residuals. The loss can only be countered by increased energy wood purchases or increased forest residue use.

*Source: Southwide Energy Committee, et al. The Pulpwood Industry and the Energy Situation; Report 80-A11. Jackson, Miss.: American Pulpwood Assoc., April 1980.

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EXHIBIT 9-1, continued.

Condition 2.7 - In the short run, the encroaching hardwood problem on much of the lands in the South can be turned into a fuel opportunity by harvesting these hardwoods for wood energy, using conventional harvesting techniques.

Condition 2.8 - Many groups are looking at the same source of wood residue in making consumption projections. Forest products plants generally are already under contract to sell their waste wood. Additionally, National Forest residues are being considered by several potential users. How these resources will be doled out has not been decided. Subsidies to small business are a definite possibility, and therefore it is presumptuous to assume that an open sale process will be used. Industry should seek to develop its own resource early in the game.

Condition 2.9 - Energy wood procurement systems similar to the existing wood procurement system of pulpwood could be used to feed energy wood into forest products conversion plants.

Relations With the General Public and Other Groups Due To the Energy Crisis

Condition 3.1 - Because of the quasi-public view of industry lands, pressure will increase on companies by private individuals to cut firewood. Unauthorized cutting of industry timber by weekend chain saw warriors will reach epidemic proportions as stout-hearted individuals refuse to pay for delivered firewood.

Condition 3.2 - The pulp and paper industry will continue to be a target for energy reduction campaigns. If the industry does not voluntarily move to significantly reduce its fossil fuel consumption, curtailments may be enacted.

Changes in Forest Management and Harvesting Operations

Condition 4.1 - Immediate system conservation measures can be exercised in harvesting and forest management activities. Integration of planning in forest management and harvesting activities will provide areas for further fossil fuel economies.

Condition 4.2 - Fossil fuel shortages may cause some shifts to more labor intensive operations in various components of the pulp and paper industry.

Condition 4.3 - Harvesting productivity must increase in the future since harvesting machines, as we now know them, are highly energy dependent. Strides must be made in the harvest of small diameter stems since all harvesting phases are extremely diameter cost sensitive.

Condition 4.4 - The harvest of forest residues to be used for energy wood with conventional harvesting equipment will be limited to larger stems. As average diameter of harvested material falls, harvest and handling costs rise exponentially. Eventually the cost of logging exceeds its value as fuel.

Condition 4.5 - Although the economics of logging limits what will be used for fuel, the restriction in utilizing encroaching hardwoods from many sites is a lack of logging capacity, not a lack of timber or technology. Logging economies preclude harvesting large quantities of extremely small material, and demands that high value products be separated where possible.

Condition 4.6 - Eventually, shorter rotations and whole tree utilization could cause degredation on some sites.

Changes in Traditional Wood Markets

Condition 5.1 - Government subsidies to energy wood development will ultimately:

1. Create a false market and distort normal market place activities.
2. Cause the value of pulpwood to rise because of new alternative markets for the pulpwood size products.
3. Will have the effect of encouraging inefficient resource allocation.

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EXHIBIT 9-1, continued.

Condition 5.2 - Fuel wood is the lowest use for fiber. As the use of wood for energy increases, the relative value of wood for fuel will increase. As the price of fuel wood goes up, so will other products. The private landowner in the future may never sell wood for less than its fuel value.

Condition 5.3 - In the short term, wood cost to pulp mills may be affected by firewood sales, especially near population centers.

Condition 5.4 - As fossil fuel prices continue to rise, exports of forest products (chips especially) will decline unless export prices rise disproportionately.

Condition 5.5 - There will be a possible loss of markets in wood where close alternatives to wood now exist, for example: concrete railroad ties, extruded particle products, laminated stock (2X4's, etc.) and electronic media replacing newspapers.

Condition 5.6 - More diverse wood based products will appear on the market as a result of increased utilization (energy efficient harvesting) of existing trees. Chip and particle board markets will expand.

Condition 5.7 - Stumpage prices to private forest owners in the future will include energy wood as a component of a sale price. Demands will be made on timber harvesters to more fully utilize the forest resource.

Condition 5.8 - Because of the difference in local market conditions, competition, etc., a local analysis must be made to determine the feasibility of wood energy systems.

Condition 5.9 - Wood theft will increase as the demand for energy wood increases.

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consequences are displayed in Exhibit 9-1 under Relations with the General Public, Changes in Forest Management, and Changes in Traditional Wood Markets.

While it is beyond the scope of this report to prove the soundness of the economic assumptions underlying these conclusions, it is important to note that they are conclusions of a big stakeholder in the wood products industry. (3)

Another Trade Association Perspective

The National Forest Products Association has issued a wood energy background paper, Exhibit 9-2.(4) It expresses the same general kinds of concerns as expressed by the American Pulpwood Association. This free market oriented association urges two roles on government: first, that the Department of Agriculture assume responsibility for improved methods of biomass production;and that the Department of Energy assume responsibility for improved technology for conversion of biomass to energy.

As reflected in the recommendations in Section 1, the strong association orientation toward a role for government suggests some promising opportunities for joint public and private ventures.

EXHIBIT 9-2

NATIONAL FOREST PRODUCTS ASSOCIATION: WOOD ENERGY BACKGROUND PAPER

The statement was a response to the increasingly popular use of wood energy as an alternative to the use of oil (especially the use of wood residues from logging, thinning and manufacturing processes.) However, the industry is concerned that this renewed public interest in the use of wood for energy will put unrealistic demands on the industry's need to have an assured flow of wood for its manufacturing processes.

1. The forest products industry will assume leadership in helping to develop an appropriate role for wood energy.
2. The policy recommends that wood and the flow of wood be allocated on the basis of economics in the marketplace.
3. The government should not set-aside federal land specifically for wood-for-energy; access to public timberlands should be all parties.
4. The government should develop programs to promote increased growth on public forestland, and eliminate incentives to grow wood for energy alone.
5. The cost of using wood for energy should be calculated on the basis of all available energy alternatives, not just oil.
6. Wood-burning power plants should be sited carefully to avoid the possibility of over harvesting the nearby forest.

The NFPA policy statement notes that the forest products industry already uses 75 million tons of wood residue every year for its own energy needs -- the equivalent of 150 million barrels of oil. The industry could probably use twice that much wood waste by the turn of the century, and pledges to take a lead role in promoting increased utilization. The forest products industry should be a primary channel for wood energy because:

1. expertise for collecting and handling wood residues is already in place;
2. to expand energy and use;
3. expanded use of wood energy frees fossil fuel for other users;
4. provides opportunity for cogeneration of electricity from renewable resource.

Implementation of this policy requires the development of improved methods for biomass production and improved technology for conversion of biomass to energy. The former requires skills/knowledge found in the Department of Agriculture, whereas the latter needs expertise on energy technology located at the Department of Energy. NFPA believes wood biomass funding, projects and programs should be organized such that DOA/USFS is the lead agency for biomass conversion to energy.

OTHER CONFLICTS

With regard to the management of most public lands, there is a tension between six competing alternatives for the use of that land:

- wilderness and wildlife preservation
- mining for energy and minerals
- timber
- grazing
- recreation
- water resources

These multifaceted conflicts are far too universal and comprehensive for consideration in this report. They are most likely to be settled on a case-by-case basis in terms of ideology, political potency of the affected stakeholders, and some intrusion of facts.

There are numerous potential conflicts which do not necessarily fit the conventional EPA criteria on effects of people or the biota, but which by indirectly effecting institutions have environmental consequences.

National Goals with Respect to Materials Policy

Increasing use of biomass for energy could, at some point, begin to drive up the price of materials such as wood. Although detailed information on cross-elasticities of demand for various materials are not available, it is clear that an increase in the price of wood relative to such materials as aluminum and plastic will result in substitutions. In most cases, the energy costs of producing alternative materials is higher than producing wood products, such as siding, pallets, or studding. Furthermore, few alternative materials are renewable or biodegradeable. Therefore, forcing such substitutions by encouraging the use of biomass may exacerbate environmental problems.

National Goals with Respect to International Trade

The United States is faced to some extent with an important trade-off involving foreign trade. By increasing the emphasis on biomass, dependence on nonrenewable sources of energy can be reduced. To some extent, imports of foreign sources of petroleum will decline. On the other hand, the nation could become a major net exporter of wood products. We are particularly well-endowed with high quality hardwoods. Use of growing stock for energy competes directly with the maturation process that leads to large, high-quality hardwoods useful for furniture or veneer.

Land Use Conflicts

Fifty-eight percent of the commercial forests in the United States is held by nonindustrial private landowners. As discussed in Section 6, page 77, this creates a potential need to monitor and regulate forest management practices at the state level to avoid large-scale exploitation of privately-held forest resources.

We see substantial institutional conflict between the need for some federal intervention on a repeated and recurrent local issue, namely forest management. By custom and statute the responsibility is in the hands of the state and local governments. The conflict comes in the sluggishness with which the state and local governments will respond, their likelihood to bend to local pressures for exploitation, and the confusing checkerboard pattern of responses that they will bring forward. This will make it difficult for large, nationally-based corporations to respond effectively or intelligently to the opportunities.

We see strong conflict driving us away from the use of the analytical tools which we have at our disposal. The situation with regard to net energy is an important illustration of this. We have a new fundamental counting tool -- namely, an examination of the quantity and quality of energy flowing through processes -- to put us in a better position to judge the long-term benefits of alternative energy development strategies. Yet, as we can see in the case of gasohol and total energy balances, short-term political forces often prevail against sound knowledge or at least submerge and suppress the development and use of that sound knowledge. An important consideration on whether or not to promote a given technology will be the question of whether or not there is a net energy gain or loss from employing that technology. A review of studies so far implies that a framework for making these evaluations is needed. This is to account for the energy costs, pollution controls, and clean-up over the life cycle of the technologies. Net energy, of course, is not simply calorie counting and caloric balances. In doing net energy and analysis, it is crucial to recognize that quantity and quality are not interchangeable. (5) Process heat, steam heat, space heat are generally low quality energy, whereas liquid fuels and electricity are high quality energy. Consequently, one must take these differences into account in any net energy assessment. For many purposes, biomass, particularly wood, is low quality energy; hence, many of the conversion processes are directed at raising the quality of the energy at the expense of the quantity. For example, a 50% conversion of wood energy into a liquid fuel might be quite acceptable, simply because that liquid fuel has a higher quality value, it is transportable, it can be used to operate automobiles, be readily stored, metered, priced, and so on.

There are substantial conflicts between short-term pressures on federal agencies and long-term national objectives. The Federal movement away from the energy plantation concept and kelp farming could be a major national loss because only when we approach a large-scale, long-range planning problem as a large-scale planning problem are we likely to develop an effective development mechanism, i.e., one based on understanding. To approach that large situation incrementally could be either impossible and hence thwart a national need, or result in environmental disruptions.

Scale Effects

One can envision that the development of these different technologies will occur on different scales and will lead to quite different sets of questions. For example, small scale decentralized use of wood as a source for home heating presents a unique set of problems in terms of pollution control options available and the regulatory process for controlling emissions. Similarly, a mass use of wood for domestic heating in a relatively densely populated urban area might create a significant, intensely localized pollution problem. On the other hand, the equivalent use in rural communities spread over larger areas might be of little consequence. From a different point of view, in order to enjoy some technological benefits, large-scale enterprise might be required. Yet there may be few routes by which investments can be applied by the private sector to achieve that scale of technology.

Different regions and local areas will present different biomass energy markets. One expects an extension of biomass to anything like a 10 to 15 quad level will result in a full range of scales of use much the way there is now a full range of scales of use of petroleum. There is no intrinsic appeal in large-scale versus small-scale in many operations such as farms and small communities. Small to very small scale operations are the only ones likely to be economically viable on farms. On the other hand, for applications such as central heating plants, larger scale operations are economic essentials for success. The conflict, therefore, is between the present structure of energy production, conversion, distribution, and marketing, and the quite different system one would require for effective biomass use. There is little likelihood of a transition from the one to the other without explicit directed Federal intervention through a broad spectrum of incentives. By no means, of course, do all incentives imply subsidies which may dislocate market structures. To put the new energy form in a competitive position with established energy forms and energy delivery institutions, government intervention may be necessary. Some intervention may:

- o reduce subsidies on competing fuels;
- o by legislation or regulation guarantee supply of wood for a significant period to stimulate investment in facilities;
- o joint research;
- o provide information to stockholders.

SECTION 10

CROPS, GRASSES, AND MANURES

PREVIEW

Crops and grasses will find their use as an energy source in one of four routes: hydrolysis followed by fermentation to alcohol; anaerobic digestion to biogas; gasification; or direct combustion.

Since the alcohol fuels route is outside the scope of this report, concentration will be primarily on biogas and gasification routes. The anaerobic digestion of crop waste in conjunction with manures is technologically practical and well established. Its adoption has to do with the local microeconomics.

As pointed out in Section 4, the overall relative contribution of this category to the national energy supply is low compared to wood. But the ability to deal with environmental problems by converting waste into economically significant feedstocks may be useful to the individual farm or processing plant.

INTRODUCTION

The United States has a well developed agronomic capability to produce crops at higher yields than almost any place in the world. However, those higher crop yields are generally associated with energy intensive agriculture. The energy intensivity comes in the form of fertilizers, pesticides, and petroleum-operated tractors and equipment. Furthermore, the maximization of crop yields, especially the notable successes of wheat and corn, depend upon matching soil characteristics, water supply, and adjuvants with carefully bred seed or plant stocks. Consequently, one cannot hope, without high costs over long times, to develop equivalent crop biomass for energy purposes in arbitrary places around the country.

Since most of the crop uses for energy would be directed at the production of ethanol -- that is, liquid fuels -- their uses are outside the scope of this report. Waste and by-products are a different story. The sources discussed in this chapter are crop waste, grass, food and fibre processing wastes, and manures.

THE RESOURCES

Crop Residues. The harvesting and processing of many food, feed and fibre crops leaves large amounts of residue: corn stover (the dried, cured stalks), rice straw, peanut hulls, cotton gin residue, wheat straw, bagasse (the material left after extraction of juice from sugar cane). Depending upon the quality of the land, from 0% to 25% of this residue is available as biomass; the rest must be left on the land primarily as protection against erosion. Surplus and spoiled crops are also a potential biomass resource.

Grasses. Prairie, pastureland, fallow land, and land that cannot sustain intensive cultivation produce large amounts of grasses annually. Marshlands support fast growing reeds and cattails; mesquite thrives in dry desert areas. Cultivation techniques appropriate to these more sensitive lands can utilize them for the specific crops that can grow under special conditions.

Grasses have the obvious appeal, at least according to some research reports, of growing rapidly and yielding large biomass tonnages per acre. In contrast to trees, they offer the opportunity for frequent harvests. They could also offer some degree of flexibility in response to alternative demands for land use and could, where competitive with wood, be a more effective soil erosion preventative.

Food and Fibre Processing Waste. The recent OTA report outlined ten major agriculture waste sources, making a total potential of 66 to 117 trillion btu's per year. This big number, of course, is only a fraction of a quad -- equal to 0.07 - 0.1 quads. Nevertheless, again as with other minor resources, the local opportunities may be significant. Cleaning up cheese whey and cotton gin trash may be an important local environmental benefit, with economic returns to the operators (1).

The cotton gin situation raises an interesting side point. It is well known that in Texas, where the bulk of the cotton gin trash is available, arsenic is used extensively on the crops. It might create a problem in energy generators. One must, therefore, generally be careful to explore pesticides and other residuals in the bioresource.

Manures. The big producers of manure are chickens, turkeys, cattle, dairy cows, and swine. Animals grazed on the open field have no current interest or significant potential as a bioenergy source -- the cost of collecting the waste would be excessive. Therefore, the two attractive alternatives are the use of manure already precollected in large scale, confined animal operations, or available on the farm in quantities convenient for harvesting and processing. The total available energy from confined animals is about 0.3 quads per year. Utilizing this for energy sources would be a positive environmental benefit since a third to a half of manure, according to OTA estimates, is washed away, lost to any practical use, or becomes an outright environmental pollutant.

QUANTITATIVE ESTIMATES

The OTA has estimated the following for the year 2000 as available resources in the categories under discussion (see Exhibit 4-9).

Crop Residues	0.8 to 1.2 Quads
Manure	0.1 to 0.3 Quads

Processing Waste	0.2 to 0.2 Quads
Grass	0.0 to 4.9 Quads

In addition to the estimates made in Section 4 on the relative yield of crops and grasses, the reader's attention is called to a symposium sponsored by Midwest Research Institute, Battelle Columbus Laboratories, and the Department of Energy on "Biomass - A Cash Crop for the Future" (2). There are several excellent discussions of biogas production from manure, including that of Biomass Institute of Winnipeg, Manitoba, (3) and an article from Georgia Tech on "Methane Generation from Poultry Manure" (4).

By and large, two factors strongly influence the ability to use these energy rich waste byproduct materials in practical ways. One is the cost of collection, and the second is the cost of transportation. Therefore, the most useful short-term resources are those which are already aggregated such as processing waste from harvesting or processing waste from food and fibre factories, or manures from penned animals.

We see crop wastes on the farm lending themselves to local applications -- either on the individual farm or in small collection sites, for the production of either biogas or for feeding gasifiers to yield methane.

Whether significant applications occur in that direction is largely dependent on:

- the relative shifts in the costs of energy alternatives;
- whether the market will move to produce low cost, effective biogas generators and gasifiers;
- federal policy, especially incentives for those advances;
- the delivery of new bioenergy information through USDA, state agencies, and agricultural schools.

We see no evidence for serious environmental problems originating from the use of crop residues for energy generation. The nation is not likely to be swept by biogas or biomass technology at such a rate that any now obscure effects of that technology could overtake us. Consequently we recommend that EPA, in conjunction with the USDA, monitor the development of the technology, and, as appropriate, begin low key, low level observation on environmental consequences.

ENVIRONMENTAL CONSEQUENCES WHICH COULD OCCUR

Environmental effects could occur at any place in the production-use cycle. Moreover, they are likely to involve adverse and beneficial effects. More specifically, there may be a tendency to over-harvest crop residues and grasses to squeeze the last bit of energy out of them. Obviously, this is not in anyone's long-term interest. It can probably be effectively dealt with in the short term by adequate information. There is no reason to believe that farmers are short-sighted and every reason to believe that they are increasingly effective as small businessmen. Information will go a long way toward helping them cope with this hypothetical problem.

A second problem may develop should economic incentives promote higher growth levels and over-harvesting of crop residues and grasses. This could stimulate greater use of nutrients and fertilizers. But the effects of runoff would be quickly noticeable. In any case, the economics of the situation make it unlikely that this will happen.

With regard to beneficial effects, either the gasifier or the biogas generator would accommodate many kinds of residues and manures and probably have a net beneficial effect in cleanup. The biogas generator would have the further advantage of producing quite satisfactory fertilizer.

Off-gas air pollution is a minimal problem. The larger the facility, the more readily it is controlled. There undoubtedly will be some problems with gasifiers from small leaks of toxic and noxious gases, carbon monoxide, hydrogen sulfide, etc. There is no reason to believe that this would become a serious environmental problem since we have had literally decades of experience with this technology and farmers are accustomed to dealing with dangerous materials and equipment.

An example of large-scale waste disposal by combustion is sugarcane residues in Hawaii. It is a big success. The Hawaii sugarcane residue story illustrates the power of necessity -- economics and fear as stimuli to innovation (5). Under those pressures, Hawaii is rapidly converting itself from nearly total dependency on imported petroleum to a substantial and ultimately complete degree of local independence.

BIOGAS

Insofar as the manure is available in wet form, it lends itself to anaerobic digestion from which one produces what is called biogas -- principally methane. Depending on the size of the operation, methane can provide space heating and steam to generate electricity. If the methane is used to operate a large system producing electricity, there is even a possibility of pumping surplus current into the utility system.

Perhaps equally, if not more, attractive in the general spirit of independent farm operations is the direct use of biogas as an energy source on the farm. According to James Butler of the U. S. Department of Agriculture (USDA):

> The energy for agricultural production today may be divided into six categories with about 30% of the energy used for field work, 25% for transportation, 20% for irrigation, 12% in livestock production, 8% in crop drying, and 5% in miscellaneous uses. The mobile operations -- field work and transportation -- will require liquid fuels whereas solid or gaseous fuels can probably be used for the

remaining four categories. (6)

We do not have a good illustration of small-scale biogas from manure in use. Exhibit 10-1 outlines the biology and the scheme of a pilot system.

Biogas as a direct heat source may be useful in crop drying and in space heating.

The practical development of biogas generators on the farm must overcome two traditional obstacles. One is the aesthetic element of handling manure, and the other is the economics of the technology. We see a significant mission for the USDA to promote research and practical development, and to encourage industry to develop practical, affordable, small-scale biogas generators.

A sense of the highly localized application and limitations on manure as fuel is revealed in a Canadian study which showed that one house in Canada in January would require in fuel and electricity:

100 head of beef cattle or

810 head of swine or

8,100 chickens or

63 dairy cattle

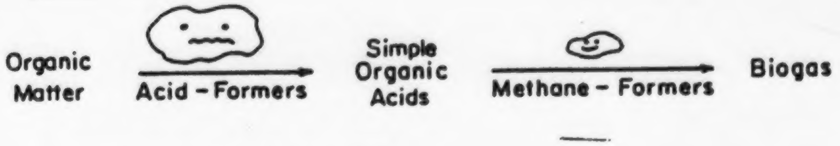
At the other extreme, the single family farm digester has been successful in China, but a primary reason for that success is the use of the small-scale biogas digesters, which in turn reflects the generally low level of energy needs of individual Chinese families. In small farm or larger facility use it is worth pointing out that nothing is lost. That portion of the biological material which is not converted to biogas remains available in the residuum as a potential fertilizer. As Bery and O'Neil of Georgia Tech have pointed out, in many parts of the country manure handling and disposal is a net cost operation, and therefore the appeal in biogas may tend to reduce a cost of disposal (7).

The alternative competing technology to biogas generation for the use of manure is the gasifier. The technology has already been discussed in Section 5.

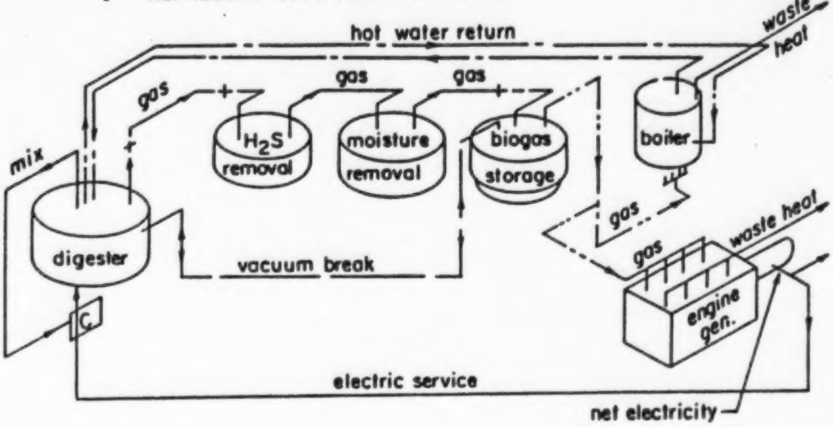
Gasifiers may be too big for use on most farms and may find their best use where there are large amounts of year around waste available as in processing plants.

In sum, the use of manure and agricultural and processing wastes is not likely, at any scale, to make any significant contributions to the net energy balance of the nation. Their use as biomass energy can become, however, one of a number of technologies significant to the individual farmer and to operators of large-scale animal feeding facilities or food and fibre processors.

EXHIBIT 10-1: THE ANAEROBIC DIGESTION PROCESS OVER-SIMPLIFIED*


Organic Matter
Acid - Formers
Simple Organic Acids
Methane - Formers
Biogas

. – REPRESENTATIVE FLOW PATTERNS


hot water return
waste heat
gas
gas
gas
mix
H_2S removal
moisture removal
biogas storage
boiler
digester
C
vacuum break
gas
gas
waste heat
engine gen.
electric service
net electricity

TYPICAL VALUES FOR ESTIMATING POTENTIAL BIOGAS PRODUCTION FROM VARIOUS TYPES OF LIVESTOCK †

	Growing-Finishing Swine	Dairy Cows	Laying Hens	Beef Feeders
Undiluted Fresh Feces plus Urine L day^{-1} 1000 kg^{-1} Liveweight	66	82	53	60
Volatile Solids Production Rate kg VS day^{-1} 1000 kg^{-1} liveweight	4.8	8.6	9.5	5.9
Fraction of Volatile Solids Converted to Biogas	0.50	0.35	0.60	0.45
Biogas Production †† m^3 day^{-1} 1000 Kg^{-1} liveweight	2.62	3.28	6.21	2.66
m^3 day^{-1} m^{-3} of digester	1.1	1.1	1.3	1.3

*Source: Biogas Energy Institute, Inc., Biogas Production from Animal Manure, report from the Renewable Energy Resources Branch of Energy, Mines & Resources, Winnipeg, Manitoba, Canada, March 1978.

SUMMARY

As it stands now the economics of the use of crop residues, and especially grass, for energy conservation work strongly against any private sector initiatives to exploit that resource. The principal limitations of the more extensive use of anaerobic digestion and gasification for disposal of agricultural and food processing wastes and manures are the cost and convenience of equipment and the general lag that one would expect in the introduction of any significant new technology to a wide number of users. There seem to be no significant environmental effects likely to occur which would not be readily discerned by present U. S. Department of Agriculture routine monitoring of farm behavior and practice. The principal need at the moment in order to enjoy the environmental benefits of improved cleanup and waste handling is for approved designs for gasifiers and digesters, more reliable cost economic data, and, on the research and development side, the application of some modern telematics techniques which we believe might substantially enhance the ease and convenience of use of both types of equipment. These missions seem to be well within the established scope of the U. S. Department of Agriculture.

We believe that it is too early for EPA to become concerned about the adverse effects of manure, and agriculture and processing wastes technology. (8)

Our net recommendation is that EPA should keep a watchful eye on this technology and engage in cooperative ventures with the USDA and state agencies.

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SECTION 11

SOME GLOBAL AND INTERNATIONAL ASPECTS OF BIOMASS ENERGY

PREVIEW

Problems of biomass energy in the Third and Fourth Worlds are substantially more important than they are in the United States. In addition to the problems which can be identified within national boundaries, there are global problems overriding all boundaries such as increasing carbon dioxide and, in the atmosphere, acid rain. As advanced nations move into heavier dependency on biomass, there will be opportunities for cross learning at the technical and public policy levels. As the global biomass energy problem becomes more important in terms of aid and trade, the already established lines of responsibility for environmental effects are likely to be unable to cope with the problems. This section offers a precis of these problems with a view toward clarifying the need for more comprehensive and integrated policy approaches by the U. S. government. The boundaries on EPA's apparent responsibilities in this area, much less its future responsibilities, are vague and uncertain. The problems are not.

INTRODUCTION

Whereas biomass is an opportunity in the United States, in the Third and Fourth Worlds it is increasingly a critical problem. But there are numerous other reasons why biomass energy is an important global problem.

Before turning to those reasons, let us briefly consider several assumptions:

- o EPA is now structured and organized around the problems of the 1950's through the mid-1970's. As new problems move into prominence it is unlikely that the present organizational structure, interest, staff commitment, organizational ambience will be fully matched to those new problems. Therefore, early anticipations may help EPA's planning.
- o It is useful to probe environmental issues which are important in their own terms even if not now clearly within or outside EPA's scope of authority in order that internal changes may be given appropriate consideration by EPA management, the Administration, and the Congress.
- o We reject the argument that international aspects of biomass energy boil down to political problems which should, therefore, be handled solely by the Department of State. There are no strictly political

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problems; problems which are politically charged often involve technological choices, hence, the need to understand possible future outcomes of alternative actions. This implies need for hefty infusions of scientific knowledge and anticipatory research into international negotiations.

AN AGENDA OF INTERNATIONAL AND GLOBAL BIOMASS ENERGY ISSUES

Not all important issues are problems. Opportunities include cross national learning on policy planning, programs, and projects. The following items briefly map the key international environmental issues likely to be more important in the next decade.

1. Carbon Dioxide in the Atmosphere (1)

The historical record shows beyond question that since the beginning of the industrial era, the amount of carbon dioxide in the atmosphere has steadily inched up from about 290 parts per million in 1850 to a current global level of about 335 parts per million. At the current rate the increase is about 0.8 parts per million per year (0.33%/year).

This increase results primarily from the massive burning of stored energy -- stored over geological time as coal, oil, and natural gas. Increased production of carbon dioxide seems to exceed the ability in oceans and plant matter to absorb the excess from the atmosphere.

The situation is further aggravated by the fact that more and more living plants are being consumed through processes of deforestation.

That is the big question about which there is now a great deal of concern, and is mediated to a phenomenon called the "greenhouse effect." Carbon dioxide has a capacity of absorbing sunlight energy and holding it within the atmosphere which, in turn, upsets the reradiation of the sun's energy hitting the earth. A certain percent of sunlight is immediately reflected. A certain other percent is absorbed and reradiated. More carbon dioxide in the atmosphere will hold more of that heat energy. The resulting impacts of an increase in temperature, however, are in dispute. The only consensus is that whatever the net effects are, they will be global in scope. When and how they will show up is unclear. The uncertainity lies in the simultaneous contributions of many different factors, both man-made and natural, including:

- Particulate emissions from fossil and biomass fuel and from natural sources such as volcanoes increase the earth's reflection.

- Emission of other gases which also contribute to the greenhouse effect, such as nitrous oxides, chlorofluoromethanes, and aerosols.

- Natural cooling trends in the long-term global climate cycle. Some projections estimate that combined with increased particulates, any warming effect from carbon dioxide will be more than counterbalanced.

The largest amount of net photosynthesis and carbon dioxide uptake occurs on land, not in the ocean as previously believed. Forests store about 90% of the carbon in land biota. The fragile and endangered tropical forests are the richest storehouses. They account for over 40% of the carbon in land plants. Forests also aid in the production and maintenance of layers of organic humus, an even greater source of stored carbon, through decay of litter.

One of the most overlooked and most vital functions of the forest may be as a buffer in the global carbon cycle. As fossil fuels are burned, carbon is released from permanent storage with no compensating replacement. Similarly, deforestation releases carbon from long-term storage, only partially replacing it with shorter term storage in smaller trees, agricultural crops, or human beings.

A major study by the AAAS has been underway for two years to codify and organize knowledge in this regard. A DOE project is well underway at the Associated Universities in Oak Ridge, Tennessee, probing issues, the scientific knowledge base, and the policy implications. Unfortunately, the Associated Universities' project has had its exploration of social impacts curtailed. Our recommendation is that EPA monitor those studies, especially the research agendas which are evolving. Of particular note is the latest compilation of thought: the October 1980 report of the April 1979 workshop on Environmental and Societal Consequences of a Possible CO_2-induced Climate Change.

2. Deforestation (2)

Deforestation is the process by which forests are cleared to such an extent or such a rate that natural recovery, i.e., regrowth, fails. Drastic effects may occur over a few seasons.

Deforestation does not merely imply the loss of trees, or the inability to solve the problem by replanting. As the land is stripped of trees, it is stripped also of the watershed, stripped of the habitat for animals and plants, stripped of the organic and nutrient cycling of the forest, stripped of the soil aeration and humus production. Destruction of the forest often carries with it implications beyond its own borders. In hilly areas, the forest ecosystem captures and gradually releases water for the agricultural lands in the watershed. If the water is lost quickly, early in the season, the land dries out faster, with later increase in the severity of floods. Erosion increases, leading to even more siltation of already clogged rivers and irrigation systems. All this leads to decreased capacity, not only of the cleared forest, but of land within the watershed.

One can divide the tropics into two zones -- the dry tropics and the humid tropics. The problems of deforestation are far more serious in the dry tropics because the processes described above operate more vigorously. In the mountainous terrain, residual humus and plant nutrients, necessary elements of forest life, are literally washed away or baked out.

Therefore, the consequences of deforestation in the highlands is not only on the forests, but also on the lowlands. Increased runoff washes away nutrients; flooding downstream, and clogging of dams and waterworks occurs.

An unexpected impact of deforestation in China has been the increase in wind speed. The response has been a program of planting shelterbelts.

Large-scale clearing of land also raises its albedo (reflection), changes weather patterns, decreases the absorption of solar radiation and decreases precipitation.

Erosion also leads to the generation of dust, which further raises the albedo and directly inhibits precipitation. This aggravates the condition leading to further degradation of the land.

The pressure on the forest comes primarily from three areas:

o clearing of land for agricultural development

o gathering of fuelwood

o commercial logging

The major initial jump in productivity from the Green Revolution has passed. Many agricultural lands in the less developed countries (LDCs) are approaching limits on yield even with modern technology. To feed the increasing population, new land must be opened up -- forested land, often the hilly, less fertile land, also the most sensitive to disruption. In areas where mobile, slash-and-burn agriculture is practiced, the fallow time has decreased to the point where the forests cannot recover. It slowly degrades beyond the point of recovery, either as forest or field. In Nepal, for instance, the population is increasing at 2.2% per year, while agricultural production is falling behind, growing at only 1.7% per year. Studies show that in Nepal the 3.4 mha of forested land are being depleted for fuel and cattle feed at an annual rate of more than 3%. However, the vast majority of wood is used for family cooking and heating. Wood provides 20% to 25% of all energy used in the developing countries. It is the world's fourth largest energy source. Over two billion people in rural populations depend on traditional fuels -- wood, charcoal, dung -- for cooking and heating. In Africa, these fuels may provide up to 95% of the energy used. The population of these areas is increasing faster than the ability of the land to support them, in either food or energy production. The latter basically means wood.

While the householders may recognize the disappearance of the forests, their immediate survival depends upon fuelwood. In Thailand, the average household used five tons of wood per year. But as the value of agricultural land rises, it drives out the forest. A shortage of fuel to warm the homes, hearths and cook pots of the poor of the Third and Fourth Worlds is the poor man's energy crisis.

Deforestation as a result of industrial harvesting is perhaps best illustrated by actions in the Amazon where an enormous floating pulp and

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paper plant is causing extensive harvesting in the forest. Related to this is the custom throughout most of the Third World of harvesting tropical hardwoods for exportation to the advanced nations. The Third World and the Third World governments are to some extent approaching the forest in much the same way that the United States approached its forests in the colonial period and the early part of last century. Forests are either an obstacle to be removed or a resource to be enjoyed often on a one-time harvest.

The wood problem is exacerbated by dung as a secondary or backup source of fuel. As wood becomes too hard to gather or too expensive to buy, families turn to burning animal waste for heat and cooking. This removes a rich natural source of fertilizer for their fields, further decreasing productivity and increasing the land pressure to expand agriculture into forested areas. The real fright of deforestation lies in such synergistic destruction. The increase in demand -- primarily due to the still rapidly increasing population -- is worsened by:

- the increase in industrialization and its accompanying energy needs;
- the introduction of energy-intensive technologies, especially in agriculture;
- the introduction of modern techniques for harvesting without the accompanying management and reforestation policies;
- the needs, especially in energy-importing countries, to export raw materials, including raw and processed lumber, for balance of payments.

These pressures are not going to let up. The existing pace of deforestation is enough to warrant drastic action -- especially with the long time needed for forestation and reclamation. It may take fifteen years for recovery to be useful. To satisfy projected demand, a five-fold increase in the current planting rate would be needed; and in some areas, such as western Africa, that need may be as high as fifteen-fold.

The U. S. and the other advanced industrial nations, notably Canada and the Scandinavian countries, may be able to have a primary impact on this localized firewood shortage through the use of modern technology and low-cost bulk shipping. Densifier and compaction technology now makes it practical on shipboard to convert raw wood into pellets or into prefabricated firewood.

We propose that a study be undertaken to examine the economics of that technology for the packaging and delivery for marketing of prefabricated firewood. One could even anticipate in special areas such as India of patterning the wood and texturing it through additives to have the physical characteristics, and hence the cultural acceptability, of native resources such as dung patties.

This proposed supplement of local firewood resources by imported wood may provide direct economic relief for these communities. More importantly, it may provide ecological relief to allow time for reforestation.

In summary, deforestation and desertification are occurring on a vast scale around the world. Separately and together they will interact with two other global problems -- meeting the food requirements of an expanding population and meeting the energy requirements of an expanding population. Furthermore, deforestation is an important factor in the changing carbon dioxide balance in the global atmosphere.

3. Food vs. Fuel (3)

As we see, food versus fuel is an inflated issue if one sees the growth of biomass energy in the United States puts their global food reserves at risk. The economics of food, hence the use of land for food production, has consistently outstripped the value of land for almost any alternative use. The exceptions are urbanization, or specialized land for the production of very high priced materials. The only way the growth of food might be sacrificed for the growth of fuel would be if questionable governmental policies created new artificial subsidies and price supports for fuel. Many argue that this is now happening with regard to ethyl alcohol production. The companion study to this report may clarify some of these questions. As noted earlier, no major examination of biomass potential, looking across all the biomass opportunities, has given great credence to gasohol fuel for the United States. Elsewhere, as in Brazil, it seems to be directed at energy independence but had its origins in the national need to level prices on food surpluses, notably sugar. In Thailand, the average household used five tons of wood per year. But as the value of agricultural land rises, it drives out the forest. Where the value of the wood is, say $70, while the rice yield of the land will bring in $400, economics makes the choice clear and promotes a version of Garrett Hardin's "Tragedy of the Commons."

As we see it, the burden falls to those who would argue that food supplies are at serious risk from the use of biomass fuels. To date, no significant evidence has been adduced in that regard.

4. Importance of New Plant Species (4)

The expanded use of biomass in the United States potentially involves the introduction of new plants from many parts of the world. It is crucial that we understand the opportunities and risks in the importation of any new species. That knowledge implies that we understand the plant's behavior in its natural habitat.

There is an extensive concern about ways to enhance forest production in the United States. Douglas fir, sycamore, poplar, southern pine, loblolly pine, and all the other common stock undoubtedly could provide much biomass. There is, however, a great deal of interest in eucalyptus, which is a tree imported from New Zealand and now widely distributed throughout California. As an imported tree, it found a very congenial environment in the United States. It grows rapidly to produce an attractive low-cost bioenergy resource. There are hundreds of other plants which have at least the superficial appeal of the eucalyptus. Some imported species may find the new

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environment so congenial that they effectively take over. They may also bear pests and diseases more difficult to control in their new environment. If we are to avoid ecological disasters by importing the terrestrial equivalent of the water hyacinth, we must have a knowledge base about the ecology of these foreign plants. Failure to develop that would quite legitimately stymie attempts at importation. Developing such knowledge would also be valuable to the rest of the world.

5. Lessons Learned (5)

The developing nations, as well as some of the advanced industrial nations, have useful lessons for the United States on biomass energy. Those lessons, however, are not likely to become known unless there is a proper receptacle and an active outreach to collect them.

Sweden may be a nation with important lessons for the United States. There is a large forest products industry in Sweden. Currently, 8% of the nation's energy is supplied by wood bark and pulp residues. The use, as in the United States, is principally within the forest products industry. There is a national policy, however, to increase the use of wood for energy sources and fast growing trees. Poplar, birch, alder, and sallow are being planted under the aegis of a so-called energy forest program.

The value of Sweden as a test bed for policy and practical experience could be significant. Another advanced nation -- with an equivalently high standard of living, an equally educated population, and as thoroughly committed to its industrial base as the U. S. -- it can look ahead and can plan for renewable resources as a mainstay of the future. They are in a major national energy debate over the two proposed alternatives to relieve its dependency on foreign oil, nuclear and solar.

At a quite different level, China, India, and other developing nations may have useful lessons in distributed small biomass energy technologies such as biogas from anaerobic digestion. China, for example, has 7.5 million biogas generators. This could be a source of useful information.

6. Other International Biomass Questions with Significant Environment Implications (6)

Several factors listed below represent either continuing lines of previous U. S. international involvement which are likely to become more important, or developments whose implications suggest the need for steady development of a base of environmental knowledge. In the absence of knowledge developed on a continuing basis, policymakers will be forced to resort to what is almost certain, on historical grounds, to be unsatisfactory, namely, crash study programs, inadequate data bases, and overly politicized issues.

- Increasingly, international boundaries are being overflown by actions of domestic national and multinational corporations. These will create new environmental challenges and problems, e.g., U. S. caused acid rain blows into Canada. As U. S. corporations continue to create problems around the world, they will become problems for the U. S. Government. If EPA does not watch for and understand these developments for these problems, who will?

- International agencies through which the United States works such as the World Bank, and domestic agencies, notably AID, are increasingly concerned about biomass. They need a better knowledge base.

- The United States has in the past and presumably will continue to be called upon by national and international organizations for assistance in science and technology. That assistance cannot be rendered if there is no knowledge base for it.

- There are issues which are themselves becoming politicized domestically but whose resolution requires a body of international knowledge which is not readily at hand. Perhaps the most striking example of that is the so-called competition between food and fuel in the allocation of land resources.

- As U. S. biomass technology and the scientific base develop, there will be a demand for export of that knowledge to assist others in aid and trade.

SUMMARY

Several international consequences of the development of bioenergy industry and more extensive distributive use of bioenergy in the United States are summarized in Exhibit 11-1.

- The introduction of great quantities of carbon dioxide into the atmosphere is a growing concern. As biomass substitutes for coal, there may be some difference in CO2 accumulation. On the other hand, insofar as biomass substitutes for nuclear, hydropower, direct solar conversion, or other processes which do not involve CO2 production, biomass will aggravate that long-term global pollution problem. Moreover, insofar as biomass is renewable presumably the CO2 produced will, on balance, be reabsorbed by growing trees to form new biomass; therefore, the problem may be self limiting, but only if the United States were the only actor, which is not the case.

- Food exports overseas may shift in their content or amount if land is converted from food production to wood production, or from food production to energy production. It is not at all clear at this point that energy uses for agricultural products would ever exceed the value for food uses.

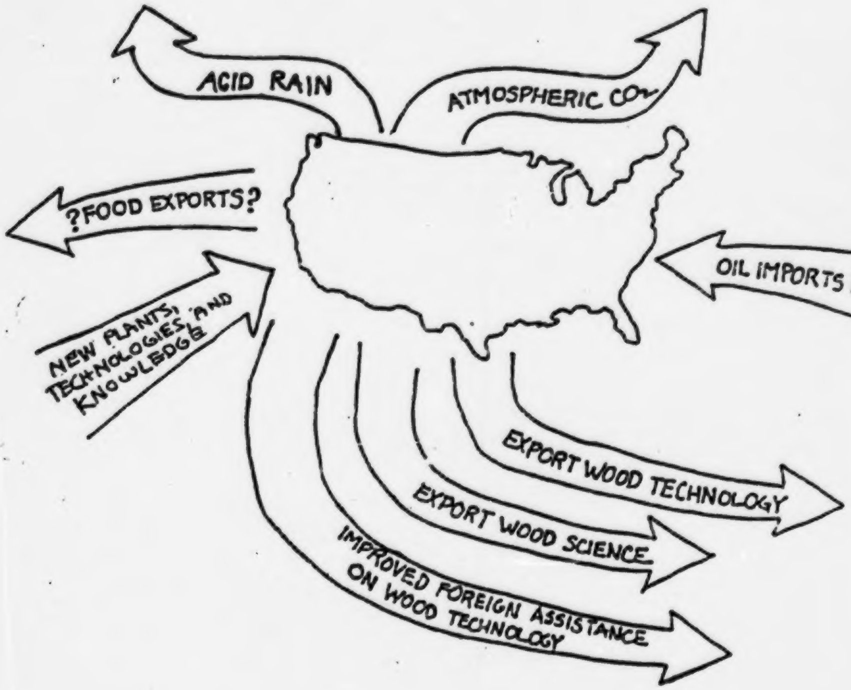
- Foreign fuel imports would go down.

- There would be a strong interest in exporting biomass, especially wood.

- There undoubtedly would be a government movement toward exporting through foreign assistance mechanisms the knowledge and the technology for using biomass.

- When biomass becomes truly large-scale, the scientific base for its manipulation, the growth and tailoring of crops, and so forth should create enough of a new knowledge to involve the export of scientific knowledge.

EXHIBIT 11-1: INTERNATIONAL IMPLICATIONS OF U.S. BIOMASS


ACID RAIN
ATMOSPHERIC CO
?FOOD EXPORTS?
OIL IMPORTS DOWN
NEW PLANTS, TECHNOLOGIES, AND KNOWLEDGE
EXPORT WOOD TECHNOLOGY
EXPORT WOOD SCIENCE
IMPROVED FOREIGN ASSISTANCE ON WOOD TECHNOLOGY

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BIOMASS: AN ANNOTATED BIBLIOGRAPHY

This short bibliography is the result of our collation of over a thousand references on all aspects of biomass, from cultivation and production systems to conversion and residue disposal. We will highlight the best references we have found; not necessarily the ones with the most technical detail, but those that represent a state-of-the art view of biomass to energy systems. We have included some general review books and symposia proceedings to provide a background on the avenues of research in biomass, and as preparation for the extensive amount of technical information on particular biomass systems.

Two excellent introductory books which survey the range of biomass feedstocks and conversion technologies and outline the outstanding environmental considerations are:

> Cheremisinoff, N.P., Cheremisinoff, P.N., and Ellerbusch, F., Biomass: Applications, Technology, and Production, New York: Marcel Dekker, 1980.
>
> Hall, Carl W., Biomass as an Alternative Fuel, Government Institutes, Inc., Rockville, Maryland, 1980.

WHY BIOMASS?

Wood and other biomass feedstocks are of interest as an energy source, both as a supplement to finite and disruptable fossil fuel supplies and as part of the popular movement towards renewable energy resources and appropriate technology. Biomass, especially in the form of wood for stoves or animal wastes for anaerobic digestion, is a common inclusion in such publications as The Whole Earth Catalog. The spirit of the alternative energy movement is summarized in a classic book:

> Lovins, A.B., Soft Energy Paths: Toward a Durable Peace, New York, Harper & Row, 1977.

The major policy issues and options associated with development of biomass energy systems are outlined in a recent technology assessment.

> Johnson, R.C., and Newman, L.C., Energy from Biomass, A Technology Assessment of Terrestrial Biomass Systems, Draft, (MTR-80W259), McLean, Virginia, The MITRE Corporation, September 1980.

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This study explores in detail the potential impacts of four biomass scenarios identified as representative of systems with likely near-term impact: gasohol from corn, residential heating with wood, methanol from wood, and industrial wood combustion.

The material directed specifically at the environmental effects of biomass energy systems is sparse, and often deals with only a specific conversion technology or a particular feedstock; in many feasibility studies and energy potential surveys, the environmental impacts are dealt with in a token page or two. The recent report by OTA does an excellent job of exploring all the potential fuel cycles, including potential contribution, technological aspects, environmental impacts, and areas for policy concern:

> Bull, T.A., et al, Energy from Biological Processes, (2 vols.), Washington, D.C., Office of Technology Assessment, July 1980.

WOOD ENERGY

Wood will make the greatest near-term contribution to energy from biomass. A standard reference that thoroughly explores the forest environment in both its "natural" state and in response to development is:

> Bormann, F.H., and Likens, G.E., Patterns and Process in a Forested Ecosystem, New York: Springer-Verlag, 1979.

This book provides a necessary backdrop for further studies on specialized aspects of utilizing the forest for energy production and a systems picture that can be used to extend the results of an impact study to general effects on the forest ecosystem.

A recent study that does an uncommonly good job of addressing environmental issues is:

> Krickenberger, K., et al, TVA's Wood-for-Energy Integrated Environmental Assessment, MTR-80W00158, McLean, Virginia, The MITRE Corporation, June 1980.

This study extrapolates two general scenarios within the TVA region: one of increased residential use of wood, and the other of emphasis on industrial conversion to wood fuels. Although the study primarily considers only the extension of current harvesting, development, and conversion practices, the environmental studies on everything from songbirds to employment patterns are thorough, and form a solid foundation for application to other scenarios and technologies of wood utilization.

An in-depth discussion of wood as a feedstock may be found in:

> Tillman, D.A., Wood as an Energy Resource, New York: Academic Press, 1978.

It covers, in great technical detail, the energy potential from wood; different species, different processing, and different conversion technologies.

The information available on producing wood for energy falls under two major technologies: silviculture, cultivating wood on farms specifically for energy production; and extension of current forest management techniques from lumber and pulp production to energy generation.

A detailed study of silviculture was done by MITRE:

> Inman, R.E., et al, *Silvicultural Biomass Farms*, (6 vols.), MTR-7347, The MITRE Corporation, 1977.

Many individual studies are being conducted around the nation on the biomass production of various species of trees, under different growth conditions. These isolated studies, some on plots as small as six trees, have not been collated into a general study on silviculture techniques.

The impact of harvesting practices on forests has been gathered in:

> Proceedings, *Impact of Intensive Harvesting on Forest Nutrient Cycling*, Syracuse, New York College of Environmental Science and Forestry, State University of New York, August 1979.

This proceedings brings together the work of agricultural and forestry scientists from USDA, universities, and both forest products and non-forest products industries. It includes work ranging from the relation between harvesting technologies and soil and water systems to the problems of acid rain ecosystems and regeneration methods. For each area of study, the research gaps are highlighted and the difficulties of extrapolating from current small-scale experiments to larger commercial systems is discussed. This report also treats the probability of cumulative error in estimation of both resource availability and environmental effects, and the validity of comparing work of different researchers in different areas of the country.

The Forest Products Research Society has also put out several publications on wood energy in the forest products industries, many in the form of proceedings of Society meetings. Reports from the USDA Forest Service Experimental Stations are excellent sources of information on current research, particularly on new cultivation and harvesting technologies.

Studies on conversion technologies are directed along two lines: dispersed, small-scale residential use, and larger-scale use by industry for process heat and power generation.

A large number of feasibility studies have been conducted for state, industrial, or private customers considering development of wood-for-energy projects. These usually include surveys on resource availability, economic and technical feasibility, and the associated socioeconomic and

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environmental effects likely to be encountered. One report that does a particularly complete job of addressing potential environmental concerns, in a readable form, is:

> Aton, D., *Wood Energy Potential in West Virginia*, Final Report on Project A-2297, Atlanta: Georgia Tech Engineering Experiment Station, November 1979.

BIOMASS OF CHEMICAL FEEDSTOCK

Biomass as a potential future source of feedstock to the chemical industry is discussed in interesting and useful detail in the more comprehensive context of all future sources of organic raw materials in the CHEMRAWN I conference.

> *Future Sources of Organic Raw Materials*. CHEMRAWN I. Papers from a conference, Toronto, July 1978. L.E. St.-Pierre and G.R. Brown, Eds. Pergamon, New York, 1980. viii, 652 pp.

WOODBURNING EMISSIONS

The best brief piece is an article by John Cooper:

> Cooper, John A., "*Environmental Impact of Residential Wood Combustion Emissions and Its Implications*," Journal of the Air Pollution Control Association, Vol. 30, No. 8, 1981, pp. 855-61.

NON-WOOD BIOMASS SYSTEMS

Marine Biomass

Marine biomass systems are still in the prototype stage; DOE and the Gas Research Institute are primary sponsors of work (conducted by General Electric) on a kelp energy farm system. Basic research into growth parameters and anaerobic digestion is ongoing at many centers, including the Lawrence Berkeley Labs and Woods Hole Oceanographic Institution. Current work is summarized in a comprehensive and non-technical form in:

> Senate Committee on Commerce, Science, and Transportation, *Energy from Open Ocean Kelp Farms*, Committee Print, Washington, D.C., GPO, September 1980.

Peat

Peat, because it can be described as either a young coal or an intermediate-term renewing energy source, has fallen between the cracks of fossil fuel and renewable energy sources research. Although not considered biomass, peat is relevant because of the potential for using peatland reclamation for creation of land for energy farming and the close relation between peat conversion technologies and those for conversion of other biomass feedstocks. A good overview of the entire process of peat harvesting for energy generation is:

> UOP/SDL, A Joint Venture of Universal Oil Products and Systems Development Corporation, A Peat Prospectus, Washington, D.C., Department of Energy, July 1979.

This short report includes an extensive reference list. Most of the work on peat is being conducted through joint efforts of the Institute of Gas Technology, the Minnesota Gas Company, and the University of Minnesota.

Ethanol

The production of ethanol from biomass is primarily directed at extending petroleum reserves by blending to produce gasohol. As a separate mini-assessment in addressing this particular topic, we will not consider it, except as it intersects the biomass systems included in our study.

Animal Wastes

Animal wastes can be anaerobically digested to produce biogas, containing primarily carbon dioxide and methane. This can be utilized directly or upgraded through commercial technologies to substitute for natural gas or purified methane (SNG). The following publication is a short description of the fuel cycle on the scale of a small farm:

> Biomass Energy Institute, Biogas Production from Animal Manure, Winnipeg: Biomass Energy Institute, March 1978.

The Energy Farm

The Energy Farm concept integrates a wood plantation with aquaculture:

> Szego, G.C., et al, The Photosynthetic Energy Factory, Warrenton, The InterTechnology Solar Corporation (HCP/T3548-01), 1977.

International

For underdeveloped nations, use of biomass fuel has become a tremendous problem as well as a potential aid to development. The southward march of the Sahara is hastened by the local people's desperate need for wood fuel. Other small nations may, through use of wood or biomass derivatives, be able to reduce their dependence on imported oil. Four informative general discussions are:

Smith, N., Wood: An Ancient Fuel with a New Future. Washington, D.C.: Worldwatch Institute, January 1981. Paper No. 42.

Donaldson, G., ccordinating author, Forestry: Sector Policy Paper. Washington, D.C., World Bank, February 1978.

World Bank, Energy in the Developing Countries, Washington, D.C.: World Bank, August 1980.

Porter, R., project director, Microbial Processes: Promising Technologies for Developing Countries. Report of an Ad Hoc Panel of the Advisory Committee on Technology for International Development, Commission on International Relations, National Research Council, Washington, D.C.: National Academy of Sciences, 1979.

QUESTIONS OF POLICY INTEREST

General

The MITRE Corporation has produced an exhaustive collection of studies on biomass-related topics, ranging from a basic technology assessment of systems to individual studies of a potential fuel source, such as methanol.

Johnson, R.C., et al, Energy from Biomass: A Technology Assessment of Terrestrial Biomass Systems, vol. 1, Report MTR-80W259, for the National Science Foundation. MITRE Corporation/Metrek Division, McLean, Virginia, December 1980.

Johnson, R.C., et al, Energy from Biomass: Background and Systems Selections for the Technology Assessment, vol. 2, Report MP-81W4 for the National Science Foundation. MITRE Corporation/Metrek Division, McLean, Virginia, December 1980.

Jones, M., et al, Energy from Biomass: The Implications of Industrial Use of Wood, vol. 3, Report MP-81W5, for the National Science Foundation. MITRE Corporation/Metrek Division, McLean, Virginia, December 1980.

Johnson, R.C., Energy from Biomass: The Implications of Methanol from Silviculture Farms, vol. 6, Report MP-81W8 for the National Science Foundation. MITRE Corporation/Metrek Division, McLean, Virginia, December 1980.

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Jones, M. *Energy from Biomass: The Implications of Residential Heating with Wood*, vol. 5, Report MP-81W7 for the National Science Foundation, MITRE Corporation/Metrek Division, McLean, Virginia, December 1980.

Johnson, R.C., *Energy from Biomass: The Implications of Gasohol from Corn*, Vol. 4, Report MP-81W6 for the National Science Foundation, MITRE Corporation/Metrek Division, McLean, Virginia, December 1980.

Salo, D., et al, *Near-Term Potential of Wood as a Fuel*. Report HCP/T4101-02 UC-61 for the U.S. Department of Labor. MITRE Corporation/Metrek Division, McLean, Virginia, August 1968.

Aubuchon, V.R., *Wood-for-Energy: A Summary Report*. Report MTR-80W370. MITRE Corporation/Metrek Division, McLean, Virginia, January 1981.

An integrated energy plan for the year 2000 emphasizing the role of biomass but finding a substantial place for nuclear and coal is the 1981 proposal of the National Audubon Society.

The Audubon Energy Plan: Technical Report. National Audubon Society, New York, N.Y. 1980

QUESTIONS OF POLICY INTEREST

Food vs. Fuel

Cultivation of biomass for energy is land-intensive, directly competing with food and fiber crops for the finite supply of arable land. Emphasis on biomass-for-energy systems will exacerbate this conflict; what effect it will have on the world food market, the energy contribution of biomass, and government action in setting land-use priorities, is still under debate. A good, concise discussion of both the domestic and international policy issues involved is found in:

Brown, L.R., *Food or Fuel: New Competition for the World's Croplands*, Worldwatch Paper 35, Washington, D.C.: Worldwatch Institute, March 1980.

The Food and Agricultural Organization of the United Nations sponsored a 1980 Conference on Energy Cropping vs. Agricultural Production. The report of that expert committee is valuable in throwing the problem in balance inasmuch as it represents a strong input from the nations thought to be most seriously affected by that tradeoff.

Biomass and CO_2

The question of the relation between biomass and atmospheric carbon dioxide has been addressed in the literature primarily from the standpoint of the global fuelwood crisis and the rampant deforestation and ensuing desertification of much of the world's land, especially in the tropical countries. A good study of the relation between the forest and the entire carbon cycle is:

> Amentano, T.V., and Hell, J., (Eds.), *The Role of Temperate Zone Forests in the World Carbon Cycle: problem definition and research needs*, Indianapolis, Institute of Ecology, February 1980.

An excellent study of the relation between carbon dioxide and global climate is:

> Woodwell, G.W., *The Carbon Dioxide Question*, Scientific American, January 1979.

MONITORING BIOMASS PROGRESS

Few publications deal specifically with energy from biomass. One that is especially valuable, not as a primary source of information, but as a guide to other reports of ongoing work, is *Biomass Digest*, published by Technical Insights, Inc. This monthly newsletter has a wealth of information on current biomass research, reporting on projects in progress, released studies, patents, and technological advances. Each issue indexes biomass-related articles published in other sources.

The Bio-Energy Council of Washington, D.C. publishes an annual Bio-Energy Directory which is an excellent source of general information on the subject.

For keeping posted on the use of wood for energy in the forest products industries, *The Forest Products Journal*, put out by the Forest Products Research Society, is invaluable. It includes in-depth reports on new harvesting, processing, and conversion technologies, maximizing the efficiency of forest utilization, and general trends in the role of wood as an energy resource.

Many solar and renewable energy publications, issued by DOE, SERI, and private groups, include biomass as part of their regular contents. *The Solar Energy Intelligence Report* provides a good overview of government (and international) activities: funding, policy trends, and research projects. *Wood 'n Energy* is a newsletter published by the Society for the Protection of New Hampshire Forests and the Wood Energy Institute. It focuses primarily on the New England area, reporting on both residential and industrial use of wood.

There are a number of regular and occasional conferences on biomass. The Bio-Energy Council sponsored Bio-Energy 80, a major comprehensive review of the state-of-the-art in the form of scores of papers.

> Proceedings, Bio-energy 80 World Congress and Exposition, April 21-24, the Georgia World Congress Center, Atlanta, Georgia, USA. The Bio-Energy Council, Washington, D.C. 1981.

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Don Klass, of the Institute of Gas Technology, Chicago, Illinois, does a comprehensive annual review of developments in biomass technology.

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APPENDIX A

SOME METHODOLOGICAL NOTES

As indicated in the introduction, Section 2, this project did not undertake any original field or laboratory research. It relied primarily upon an examination, collation, and analysis of the published research of other organizations. It did a synthetic and critical examination of those reports as its contribution to the policy and research planning discussion. This report was strengthened by a review and outreach process to collect, correct, and organize its material and to critique its findings and recommendations.

The purpose of this appendix is to indicate more specifically some of the conceptual elements entering into that critical analysis and synthesis.

Two obviously important analytical tools were not brought to bear in this study for reasons mentioned in Section 3. They do merit further note in this appendix, however. The report did not undertake an economic analysis at any level of important questions associated with the production of biomass energy, or in the inter-convertibility or interfuel competition in the long and the short run. More specifically, it did not look at the question of alternative public policy actions as primary influences on the interfuel competition. Public policies, particularly at the Federal level in terms of incentives, tax write-offs, technological support, information transfer, and subsidies could have a far more important effect on the development of biomass as fuel than current market economics.

The second obvious area the study did not undertake was a forecast of near and long-term demand (five to forty years) for biomass energy, simply because it was clear from the work of others, notably the Mitre Corporation and the Congressional Office of Technology Assessment, that such forecasts would be highly unreliable. That unreliability to a substantial degree is dependent upon the uncertain economics of the public policy toward biomass energy. The long-term demand for biomass is further perturbed by the uncertainties of the international politics of fuel availability and supply and is further compounded by the short-term perturbations which may occur in interfuel competition as a result of new discoveries of oil or gas, cracking of OPEC's united front and a series of other short-range (0 to 5 years) developments which may defer attention to long-term national energy policy initiatives.

The remainder of this appendix deals with four items:

- some general principles of a scientific and technological sort which should help the reader and which helped the analysts understand the complexities of the problem;

- some nine general principles underlying the search for environmental consequences. These general principles are applicable to any technology;
- some eleven generic causes of environmental problems identified and discussed in EPA's Research Outlook 1980;
- a so-called "phase demand matrix" which systematically suggests where to search for impacts as a new technology moves through a full cycle of development from initiation through close-down or obsolescence.

The detailed use of these conceptual tools in our analysis and synthesis is muted in the report, simply because to tease out each step at each stage in detail would create an overwhelming burden of inconsequential minutia and obscure the general pattern of findings, conclusions, and recommendations.

THREE GENERAL PRINCIPLES INFORMING THE SEARCH FOR CONSEQUENCES OF BIOMASS

Several principles having to do with chemistry and the energetics of biomass are one firm basis for understanding the broad scope of the potential applications of biomass and the reasons why economics of biomass are so complex. Among these principles are the following:

- All energy is interconvertible. Heat, light, electricity and other energy from biomass, hydropower, nuclear power, coal, oil, and natural gas are technologically interconvertible. The choices within that mix are driven by the state of the technology, short- and long-term microeconomics, government policy, and innumerable other factors such as market inertia, uncertainty, and inflation.
- All organic chemical feedstocks are interconvertible in principle. Interconvertibility has tended to be mediated by a small number of basic organic chemicals. So, for example, one can make ethanol and ethylene from any coal, petroleum, or biological feedstock. Likewise, one can make methanol (wood alcohol) from any of those feedstocks. The core determinant in using that potential for interconvertibility is cost. Cost is determined by raw materials, technology, and the scale and capacity of equipment. Many well-known and well-understood principles of chemical engineering practice and microeconomics operate here.

  The basic consequence from the above two principles is that simply because something can be done is not a sound argument that it should or will be done.
- Flexible, multi-faceted systems generally are more robust and resistant to external changes than are single technology systems. This principle is widely recognized now in the growing argument for energy independence premised upon a diversity of energy sources and

energy technologies. It also is an underlying principle in the advocacy of decentralization and smaller scale enterprises. Unfortunately, in the short run, economics tend to militate against what in the long run would be an attractive component of a diversified mix.

PRINCIPLES UNDERLYING THE SEARCH FOR ENVIRONMENTAL CONSEQUENCES OF ANY TECHNOLOGY

There are nine principles generally useful in the search for effects of any technology. See Exhibit B-1. There are also those more specifically associated with the search for effects on people, the biota, and the techno-economic structure. See Exhibit B-2.

The principal effects of any major technology result from three characteristics of every new technology.

- First are the direct effects of the technology from the production of raw materials to the transportation, use, and disposal of waste materials.

- The second set of effects results from the new technology almost always being a substitute for a previous technology. Consequently, there are effects resulting from the withdrawal or removal of that which is substituted for.

- Third and most significant in many cases, a new technology carries capabilities which often bear little relationship to the reasons for the initial substitution, but which later become important as the technology moves to a larger scale or becomes more commonplace or cheaper.

These three principles can be illustrated by the automobile. We are well aware of the direct effects of automotive technology in terms of requirements for resources, effects on land-use patterns, the production of air pollution, and issues of solid waste disposal. Much of the discussion of the effects of automobile technology deals with the direct consequences of the technology. The substitution effect of the automobile is illustrated by the relief it provided for the problem of horse manure in cities. The concentration of large numbers of horses had created an environmental nuisance and a health problem.

As a general guideline we see that in order to find relief from a significant environmental problem, the individual or set of remedies must have an effect well beyond a 10 or 15 percent change in the pollutant. We see that the relief must come at the level of 80 to 99 percent. By and large, it is difficult to define, except in a quite arbitrary way, a threshold for an environmental problem, reliable within less than 10 or 15 percent. Consequently, a low level of change is not likely to be worth the cost, unless those were numerous low level changes which can be orchestrated or integrated to have a big collective effect. To illustrate the point, a 10 percent reduction in solid waste production or a 10 percent reduction in solid waste

EXHIBIT B-1: NINE PRINCIPLES USEFUL IN SEARCHING OUT THE IMPACTS OF A TECHNOLOGY

1. A Technology Has Direct Effects.
2. A Technology Has Effects Upon That Which It Replaces or Substitutes For.
3. Major Technologies Involve New Capabilities Which Often Have The Most Significant Long-Term Effects.
4. Scale, That Is, The Size Of An Enterprise, Can Itself Have Major Consequences.
5. Technology Is Neither Good Nor Bad, Nor Is It Neutral (Kransberg's Law).
6. Indirect Effects Develop Slowly And Are Usually Outside The Interests Of The Links In The Chain Of Buyers And Sellers.
7. Lead Time Is Very Good. It Gives Time To Plan And To Act.
8. Systems Effects Are Easier And Cheaper To Correct At The Beginning.
9. Structural Effects On Society Are More Important Than The Short-Term Microeconomic Consequences.

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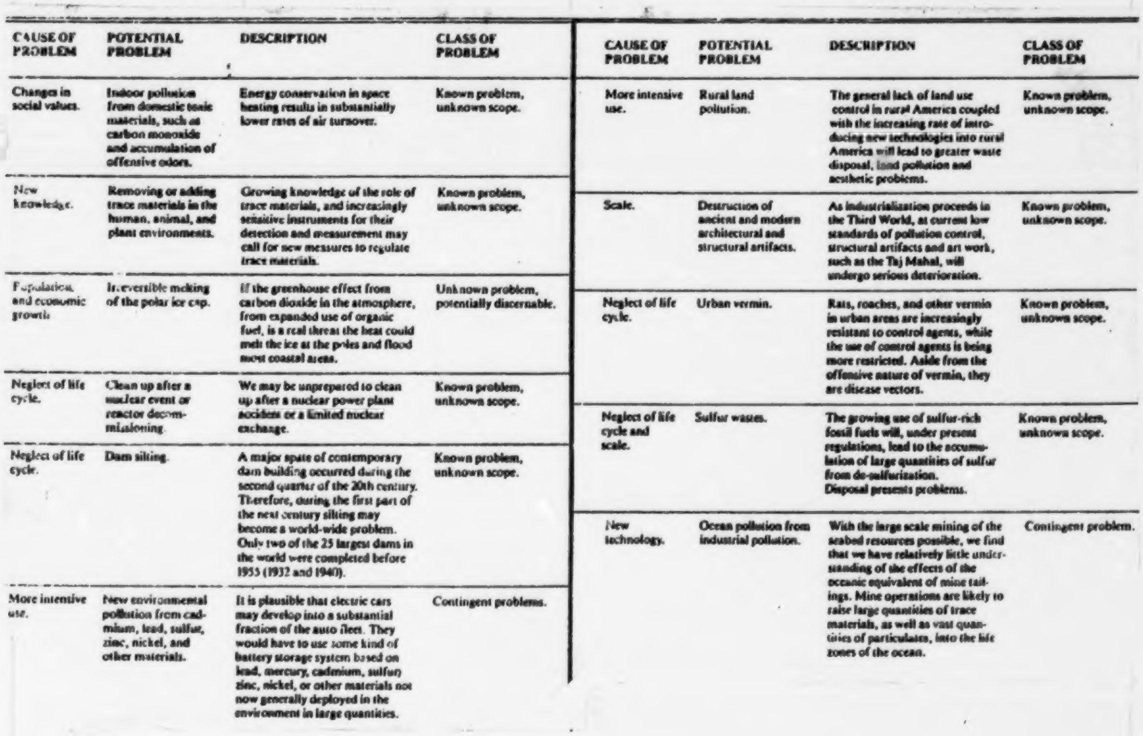
burial in the New York area would have little consequence. A 10 percent reduction in air pollution in Los Angeles would have little effect. In order to substantially relieve the problem, the sum of all changes must be much higher. This point is particularly important in connection with biomass, since many see biomass as a substitute for nuclear or fossil fuels. Hence, it is seen by some as a way of relieving or circumventing their environmental disabilities. Certainly, at the national level, it is unlikely as discussed in the text that biomass could have that kind of substitution benefit. On the other hand, at the local or regional level, substitution effects of wood biomass could be quite substantial. Insofar as wood or other biomass is substituted for petroleum or natural gas, it would modify the amounts and mix of air pollutants and solid waste (ash).

The automobile also illustrates the third effect -- that of new capabilities. The auto provides portable privacy. That portable privacy changed courting behavior. Another capability of the automobile is flexible transportation, as opposed to the more rigid transportation routes of trolley lines and rail systems. That flexibility promoted the dispersal of the population and the further separation of living space from the work place.

Employing these three principles -- direct effects, substitution effects, and new capabilities -- is a fruitful way to probe the potential impacts of biomass.

EXHIBIT B-2: CLASSES AND CAUSES OF FUTURE ENVIRONMENTAL PROBLEMS*



CAUSE OF PROBLEM	POTENTIAL PROBLEM	DESCRIPTION	CLASS OF PROBLEM
Changes in social values.	Indoor pollution from domestic toxic materials, such as carbon monoxide and accumulation of offensive odors.	Energy conservation in space heating results in substantially lower rates of air turnover.	Known problem, unknown scope.
New knowledge.	Removing or adding trace materials in the human, animal, and plant environments.	Growing knowledge of the role of trace materials, and increasingly sensitive instruments for their detection and measurement may call for new measures to regulate trace materials.	Known problem, unknown scope.
Population and economic growth	Irreversible melting of the polar ice cap.	If the greenhouse effect from carbon dioxide in the atmosphere, from expanded use of organic fuel, is a real threat the heat could melt the ice at the poles and flood most coastal areas.	Unknown problem, potentially discernable.
Neglect of life cycle.	Clean up after a nuclear event or reactor decommissioning.	We may be unprepared to clean up after a nuclear power plant accident or a limited nuclear exchange.	Known problem, unknown scope.
Neglect of life cycle.	Dam silting.	A major spate of contemporary dam building occurred during the second quarter of the 20th century. Therefore, during the first part of the next century silting may become a world-wide problem. Only two of the 25 largest dams in the world were completed before 1955 (1932 and 1940).	Known problem, unknown scope.
More intentive use.	New environmental pollution from cadmium, lead, sulfur, zinc, nickel, and other materials.	It is plausible that electric cars may develop into a substantial fraction of the auto fleet. They would have to use some kind of battery storage system based on lead, mercury, cadmium, sulfur zinc, nickel, or other materials not now generally deployed in the environment in large quantities.	Contingent problems.
More intensive use.	Rural land pollution.	The general lack of land use control in rural America coupled with the increasing rate of introducing new technologies into rural America will lead to greater waste disposal, land pollution and aesthetic problems.	Known problem, unknown scope.
Scale.	Destruction of ancient and modern architectural and structural artifacts.	As industrialization proceeds in the Third World, at current low standards of pollution control, structural artifacts and art work, such as the Taj Mahal, will undergo serious deterioration.	Known problem, unknown scope.
Neglect of life cycle.	Urban vermin.	Rats, roaches, and other vermin in urban areas are increasingly resistant to control agents, while the use of control agents is being more restricted. Aside from the offensive nature of vermin, they are disease vectors.	Known problem, unknown scope.
Neglect of life cycle and scale.	Sulfur wastes.	The growing use of sulfur-rich fossil fuels will, under present regulations, lead to the accumulation of large quantities of sulfur from de-sulfurization. Disposal presents problems.	Known problem, unknown scope.
New technology.	Ocean pollution from industrial pollution.	With the large scale mining of the seabed resources possible, we find that we have relatively little understanding of the effects of the oceanic equivalent of mine tailings. Mine operations are likely to raise large quantities of trace materials, as well as vast quantities of particulates, into the life zones of the ocean.	Contingent problem.

*Source: "Anticipating Future Environmental Problems," Research Outlook 1980, U.S. Environmental Protection Agency, Office of Research and Development.

A fourth principle has to do with scale. As enterprises become larger, environmental effects are likely to become more severe as they, in one way or another, approach and exceed the recover capacity -- the so-called carrying capacity -- of the local environment. Scale effects, however, may come in several forms. There may be large single facilities, in the jargon of the environmental discussion -- point sources. An example of a diffuse source is automotive air pollution. Therefore, scale effects are not of uniform importance or common origin. Scale effects from point sources lend themselves to more ready control -- from a technological, regulatory, and a public administrative point of view. In contrast, large-scale but diffuse sources are extremely difficult to control. Historically one sees this in the case of the cities of England where coal became a major problem because it was burned in individual residences. With regard to wood, effluents from large central facilities will be more environmentally benign than the effluents of an equivalent amount of biomass in a large number of small facilities. Central power stations are likely to be less air polluting than residential wood stoves.

A fifth principle is that costs and benefits are generally too narrow a framework for evaluating the most important effects of a technology. As Melvin Kranzberg, the historian of technology, is fond of pointing out, "Technology is neither good, nor bad, nor is it neutral." As he points out:

> Kranzberg's First Law is not quite so contradictory as it sounds. Consider, for example, the hammer, which can be used for constructive purposes such as hitting one's neighbor over the head. But the real point of Kranzberg's First Law is that technology is embedded in a larger social system, affecting--and affected by--values, institutions, economic and political systems, and the like. It interacts with those, sometimes in a fashion unforeseen by its original creators.
>
> Thus, for example, Henry Ford thought his Tin Lizzie would help bring the farmer to the city and provide cheap personal transportation for large numbers of people. It did that--but also much more. It created two of America's greatest industries: those concerned with the production of automobiles and petroleum. In addition to being the favorite means of transportation and the foundation of the American economy, the mass-produced automobile changed American living patterns. The middle class moved from the crowded city to suburbia and exurbia; the nature of leisure activities changed, as did accessibility to them. Within a half-century of Ford's development of the moving assembly line to produce the Model T, American work and play had become dependent upon automotive transportation. America was "locked in" to the private automobile. It had become much more than a "neutral" technical instrumentality, largely because of the way it has interacted with other elements of human values and social institutions.1/

The most significant technologies involve an inextricable mix of benefits and costs. A usual further complication is that benefits and costs are often aggregated and disaggregated in ways that are not congruent. Therefore, the beneficiaries of a central power station are not necessarily the ones who are suffering the penalties of having it close by. The third element in Kranzberg's notion, that technology is not neutral, raises the important point that the more significant the technology is, the more likely it will have long-term effects that change the framework of the discussion. New socioeconomic, technological, and environmental options and effects arise which do not fit the old categories. In this regard one might anticipate that should biomass energy develop into a major technological capability changes could occur which might be as important as the biomass energy itself. For example, biomass could become the basis for a chemical industry.

As a sixth principle, the derivative or second-order effects -- the down-stream effects -- rarely develop instantly and in parallel with the introduction of the new technology. To illustrate again with the automobile, the negative environmental effects began to accumulate well after the pattern of automobile design and use had become fixed. The second-order effects slowly matured as those initial designs propagated and froze.

1/ Kranzberg, Melvin, ed. Ethics in an Age of Pervasive Technology, Westview Press 1980, Boulder, Colorado, pp. 13-14.

A seventh principle closely paralleling the above is that lead time is good. Lead time is time to plan and to introduce new knowledge into public discussion -- to weigh and evaluate choices for controlling undesirable and promoting desirable effects of the new technology. Lead time has often been wasted simply because inadequate social mechanisms exist for conducting the anticipatory learning.

A principle of paramount economic importance is that it is generally easier, more straightforward and cheaper to introduce systems changes and technological changes earlier rather than later in the development of a technology. For example, it is generally cheaper to build a factory with environmental and safety controls in it, than it is to retrofit. This principle argues strongly for early and better understanding of the impacts of any new technology.

A ninth principle is that the systems effects of a new technology are generally more important than the short-term effects involving the various links in the chain of buyers and sellers, producers and consumers. Unfortunately, systems effects at the early stages often are so subtle and difficult to detect and interpret that they tend to be ignored. For example, each actor in the drama was quite willing to introduce antibiotics into the animal food chain in order to increase productivity. Yet the systemic effect was to increase the risk to all animals, and hence to people, of more intractable and more serious diseases. In general the systems consequences tend to be variations on Garrett Hardin's well-known "tragedy of the commons."

SOME GENERIC CAUSES OF ENVIRONMENTAL PROBLEMS

There is a great body of organized experience on the historical origins of the contemporary problems of air, water, solid waste, noise, and aesthetic pollution. EPA's Research Outlook 1980 documents many of these factors at a generic level in the chapter "Anticipating Future Environmental Problems." Eleven generic causes of environmental problems were identified and classified according to how well the scope of the problem is understood. A summary is shown in Exhibit B-2. The results of probing for these general sources of environmental problems were presented in the body of this report. Here it is enough to note that they were the exploratory guidelines for identifying environmental effects.

THE PHASED DEMAND MATRIX

A complementary and systematic way to both probe and present important potential impacts of a new technological system is premised on the well substantiated, empirical observations that most new technologies go through a five-phase evolutionary development:

- the first phase, initiation, includes planning, pilot work, demonstration projects, statement of objectives, etc.;
- the second phase has to do with implementation, citing, procurement, construction;

- the third and longest phase is the operation of the new technology and its associated inputs, processes, by-products, emissions, transportation, etc.;

- the fourth and general phase involves the use of the technology or its products and its potential misuse and abuse;

- the fifth and last phase of every technology, every facility, every physical artifact is close down, discard, obsolescence, phase-out, or decommissioning.

With regard to each of these phases, empirical knowledge says that there are likely to be effects on capital, labor, land-use, energy, materials, the environment itself, skills, and institutions. These key impact areas and the phases are displayed in Exhibit B-3. They can be used as a probing instrument, a check list, or a reporting format.

EXHIBIT B-3: PHASED DEMAND MATRIX FOR THE IDENTIFICATION OF POTENTIAL IMPACTS*

	Demands On:							
Phase/Development	Capital	Labor	Land	Energy	Materials	Environment	Skills	Institutions
Initiation								
OBJECTIVES, POLICY, PRIORITIES								
R&D: BASIC, APPLIED								
INNOVATION: TECHNICAL, LEGAL, ETC.								
PLANNING, DESIGN								
PILOT PLANTS								
DEMONSTRATION PROJECTS.								
Implementation								
CAPITAL INVESTMENT								
SITING								
PROCUREMENT								
CONSTRUCTION								
Operation								
INPUTS								
PROCESSING								
PRODUCTS								
BY-PRODUCTS								
EMISSIONS								
TRANSPORTATION								
Utilization								
DISSEMINATION, USE								
MISUSE, ABUSE								
Closedown, Obsolescence								

*Source: Vary Taylor Coates, Ph.D. at The George Washington University

APPENDIX B

STATEMENT OF WORK*

RFD-DV-80-A150

Title of Project: Mini-Assessments for Selected Future Environmental Problems

The contractor shall furnish the necessary personnel, facilities and/or equipment to perform mini-assessments for the following topic(s):

(The selected topics upon which contract award is based will be listed here at time of award.)

The topics listed above are further described below:

Each mini-assessment is intended to provide OSASS sufficient information to support well-informed research priority and resource allocation decisions. To meet this requirement, the contractor shall produce a report which summarizes the state-of-knowledge concerning the problem, including defining and scoping the problem in terms of its public health, public welfare and environmental policy implications and identifying major information/knowledge gaps and inadequacies in analytical methods and techniques. These problem identification and definition (or "white-paper") reports will be used to stimulate discussion of the problem and to facilitate reaching a decision as to whether further study is warranted.

In performing mini-assessment, the contractor shall coordinate closely with the OSASS staff, including preparation of a final work plan, a draft final report and a final report. Since these mini-assessments are inherently interdisciplinary, the contractor is expected to use an interdisciplinary team and approach appropriate for the topic being assessed. The contractor shall also provide the necessary support staff and facilities.

Task one - Preparation of Work Plan

Within two weeks following award of the contract, key members of the contractor's interdisciplinary team shall meet with the OSASS project officer to discuss the work plan included in their proposal and modifications to be made to make it a work plan satisfactory to OSASS. The work plan shall include a description of the study, its boundaries, the approach, and major data sources to be used and a time schedule. Ten copies of this work plan

*April 18, 1980

shall be delivered to OSASS no later than five working days following the meeting with the OSASS project officer.

Task two - Assessing the Problem

The objective of the mini-assessment studies is to produce information which will help EPA decide whether a potential environmental problem is actually likely to occur, whether it is likely to be a significant problem, and, if it is, whether further research resources are being allocated. To provide a report which meets these objectives the assessment shall, at a minimum, include the following:

- Background and literature review of the problem;
- Description of the probable development of the problem including likelihood, magnitude and consequences;
- Identification of interested parties, decision makers, organizations and experts involved;
- Description of trends which may affect public health, public welfare and existing or planned environmental policies and regulatory strategies;
- Description of the degreee of confidence and certainty of data, methods and findings;
- Identification of major information and knowledge gaps and inadequacies in analytical methods and techniques; and
- Identify research which should be conducted to support the agency's regulatory mission.

Task three - Preparation for Final Report

Once the information has been assembled and analysis is underway, the contractor shall meet with OSASS and discuss a summary of the study before work on the final draft report begins. At this meeting OSASS personnel will aid the contractor by providing information relating the topic to the EPA mission, activities and policies.

INCREASED USE OF WOOD AND OTHER BIOMASS AS SOURCES OF ENERGY

The concept of using wood, or other biomass, as a source of heat on an industrial level as well as in private homes is attractive since: (1) wood is a renewable energy source; (2) it may result in less noxious environmental pollutants; and (3) it is an indigenous energy source. Numerous studies have been conducted or are in process to determine the efficiency of wood burning devices and to identify the amounts and types of pollutants released as well as possible health effects.

After reviewing the technical aspects involved, this assessment should attempt to identify the social, institutional and economic factors which will affect the substitution of wood or other biomass for coal or oil as a direct source of energy.

Based on the accumulated information and analysis, the contractor must develop an overview of the problem, expand the existing data base and evaluate pertinent concepts, models, analytical methods and environmental policies as they affect the use of wood as an energy source. This should result in a comprehensive, integrated overview of the long-term regional and national outlook.

The final report must summarize the existing state-of-knowledge and define and scope the potential for growth and likelihood in terms of social and institutional factors which have been determined to be of significance. The report must also address the public health, public welfare, and environmental policy implications and identify major information/knowledge gaps and inadequacies in analytical methods and techniques.

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APPENDIX C

WORKSHOP PARTICIPANTS AND ACKNOWLEDGEMENTS

Any project as broad in its scientific, technical, economic, and policy connections as this one on the implications of biomass for energy, profits tremendously by continuing evaluation and criticism from every quadrant.

Early in this project we met with the OSASS staff.

When the first draft report was available, an all day review and workshop was held on April 8, 1981, involving some 24 people in addition to our own staff. They were:

Julia Allen - RFF
Chuck Bohac - TVA
David Burns - AAAS
Raymond Costello - DOE
Gregory D'Alessio - DOE
Dan Deudney - Worldwatch Institute
John Elwood - International Paper Co.
Jack Fritz - AID
Dexter Hinkley - IR&T
Peter Hockstra - U.S. Forest Service
Karen Hughes - NSF
Robert Jamison - Weyerhaeuser Co.
Jack Hornick - U.S. Forest Service
Channing Johnson - Mitre Corp.
John Loney - TVA
Tim Marty - Bioenergy Council
John Muench - National Forest Products Assoc.
Lawrence Newman - Mitre Corp.
Charles Oakley - EPA
Michael Osborne - EPA
Steven Plotkin - OTA
Paul Schwengels - EPA
Carter Kiethley - Wood Heating Alliance
Charles W. Vail - Biosys Inc.

The workshop was in two phases: the morning was given over entirely to a round robin of praise and criticism, which did much to highlight the implicit tensions among the interests, needs, and perspectives of various stakeholders. As a result of the critical comments, we scrapped the first draft and the pattern for its preparation. It was structured as a catechism of biomass energy. Some three hundred questions and answers systematically probed all aspects of the field. The afternoon session was devoted to the exploration of impacts, consequences, and issues in small group workshops.

On April 15, 1981, we enjoyed the benefits of a sit down review workshop with the OSASS office. EPA staff present included John Reuss, Morris Levin, Charles Oakley, James L. Regans, David Bennett, John Agosta, and James Sullivan, all of OSASS, and Seymour Holtzman, the Health Effects Coordinator of ORD.

With the preparation of the final draft report, copies were sent to a number of reviewers, some of whom were lavish in their time and criticism.

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Among the reviewers providing written comments on one or more drafts of our report were:

W. F. Schoen - ARCO Petroleum Co.
John Stinson - TVA
Donovan Forbes - TVA
Dennis McCarthy - TVA
Seymour Holtzman - EPA
John Loney - TVA
Chuck Bohac - TVA
Karen Hughes - NSF
Carter Kiethley - Wood Heating Alliance
Paul Schwengels - EPA
S. Plotkin - OTA
R. Costello - DOE
G. J. D'Alessio - DOE

In addition to those noted in the above connections, acknowledgement for assistance and help is also due to:

Frank Maslan, independent consultant
Larry Tombaugh, Michigan State University
V. T. Coates of J.F. Coates, Inc.

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